Greenhouse Forcing from Short-lived Gases and Aerosols: Uncertainties due to Geographic Variability and Indirect Effects

Michael J. Prather
Earth System Science Department
University of California, Irvine

Black Carbon Emissions and Climate Change: A Technical Workshop
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Short-lived Gases and Aerosols

Atmospheric Composition and Radiative Forcing

- primary impacts are immediate and close to home
- secondary / indirect impacts are more far reaching

Comparison of Radiative Forcings

- evolution of the bar chart
- history of radiative forcing for short-lived agents

Climate Response

- climate sensitivity to different types of forcing
- comparing global/regional climate changes

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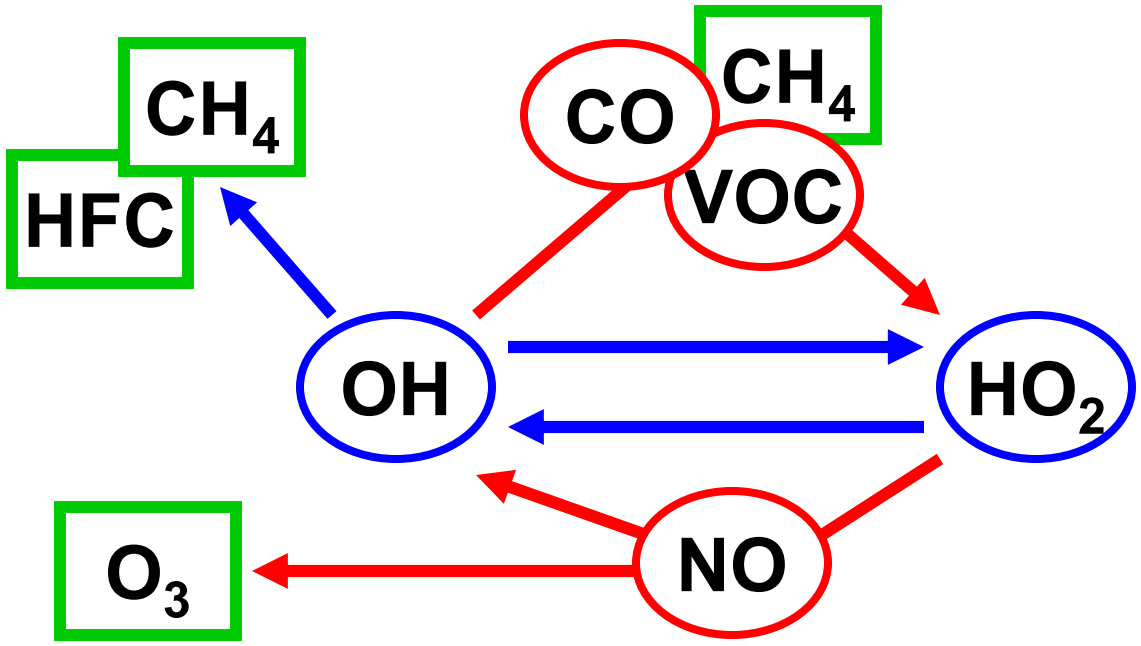
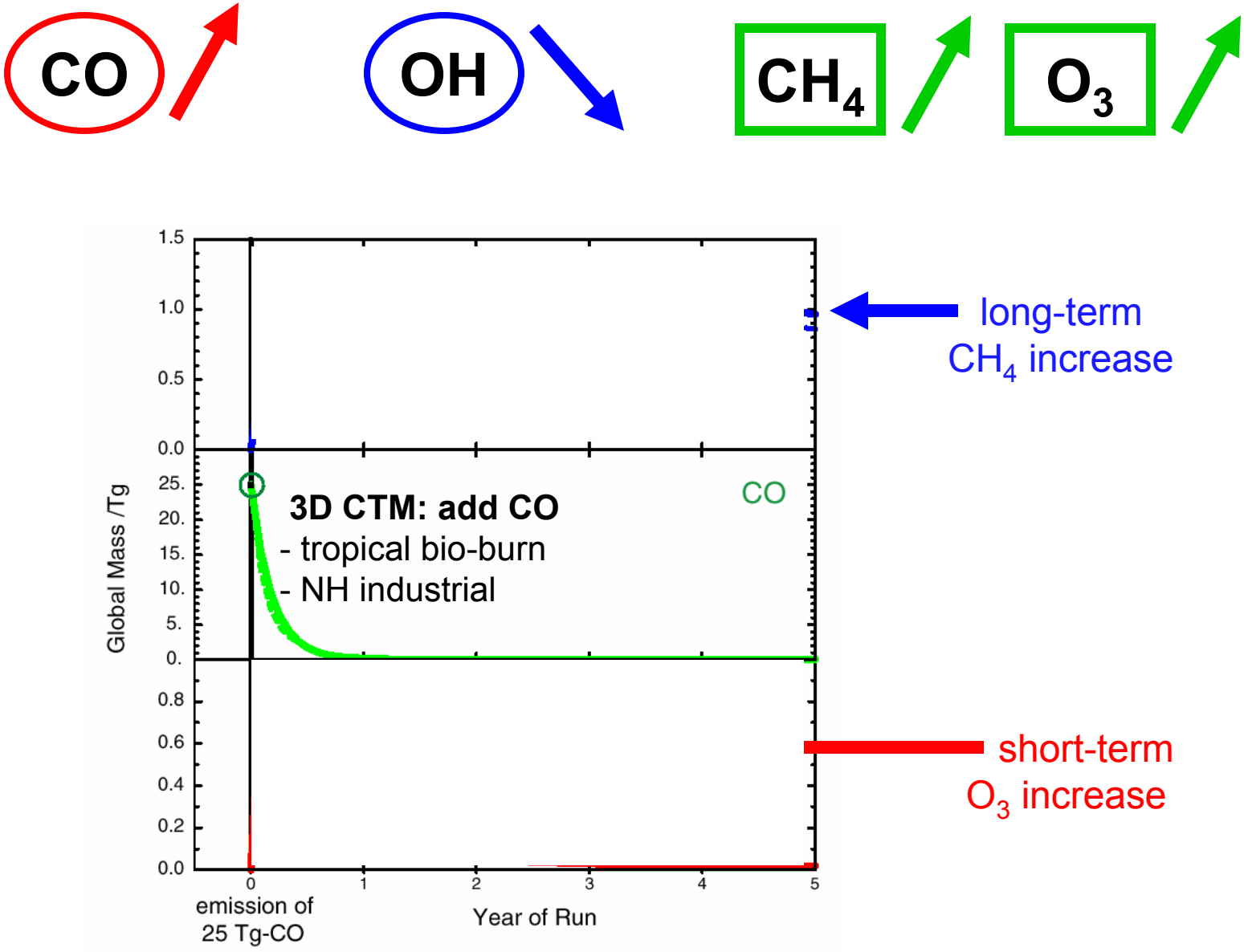
*How do **criteria pollutants** impact **greenhouse gases** ?*



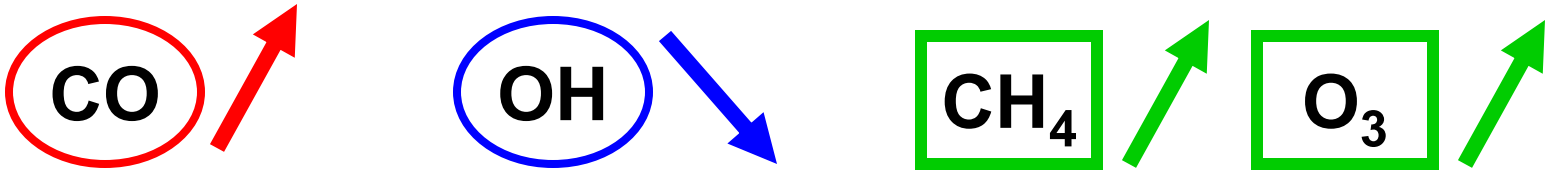
CO, VOC, NO_X *(=NO+NO_2)*, & CH_4 control

tropospheric chemistry

which is the sink for CH_4 & HFCs; the source for O_3


CO
OH
CH4
O3
1.5
1.0
0.5
0.0
25.
20.
15.
10.
5.
0.
0.8
0.6
0.4
0.2
0.0
Global Mass /Tg
3D CTM: add CO
- tropical bio-burn
- NH industrial
CO
long-term
CH4 increase
short-term
O3 increase
0
1
2
3
4
5
emission of
25 Tg-CO
Year of Run

CO becomes an indirect greenhouse gas



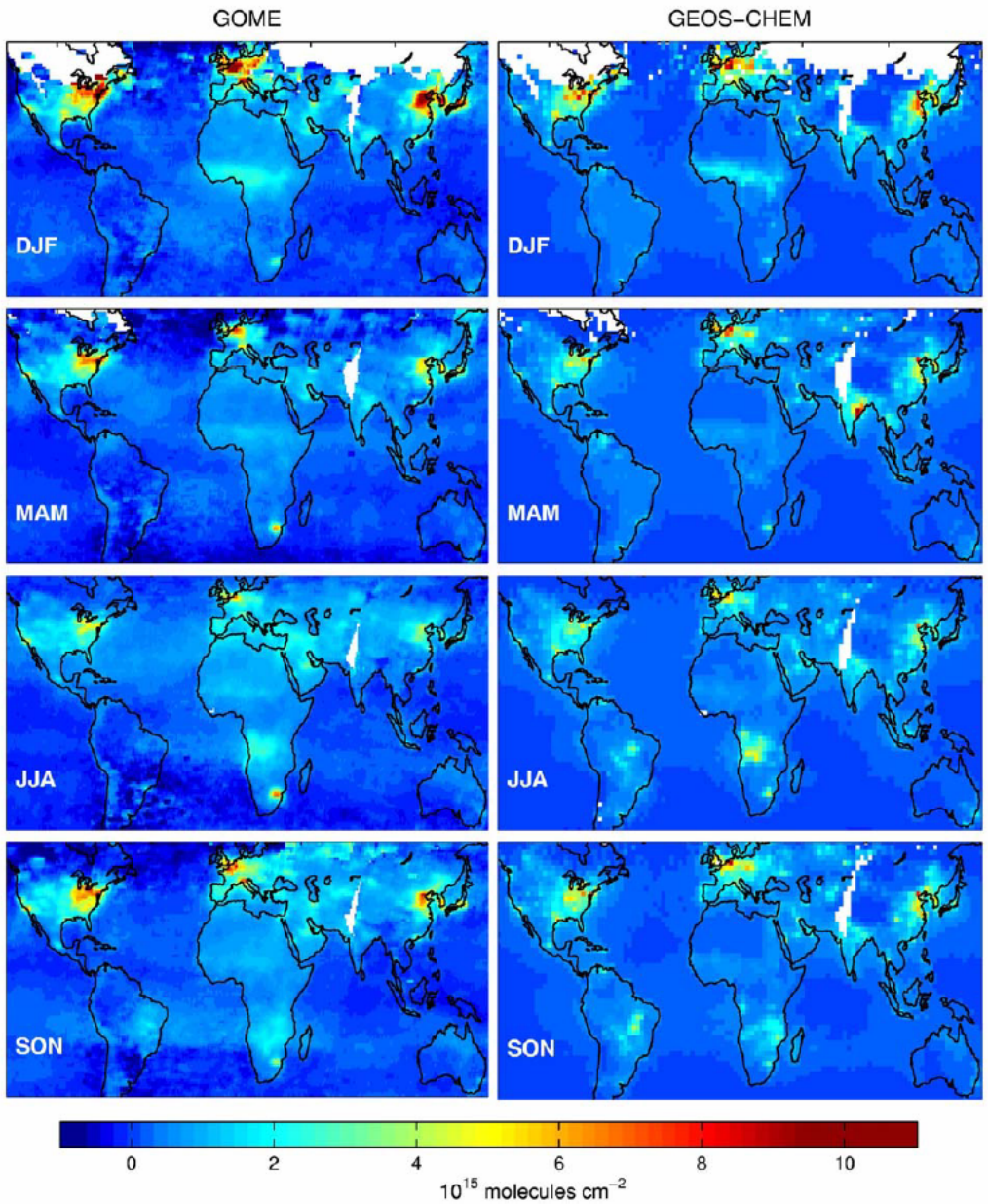
CO emissions are effectively equivalent to CH_4 emissions:

100 Tg-CO = 5 Tg-CH4

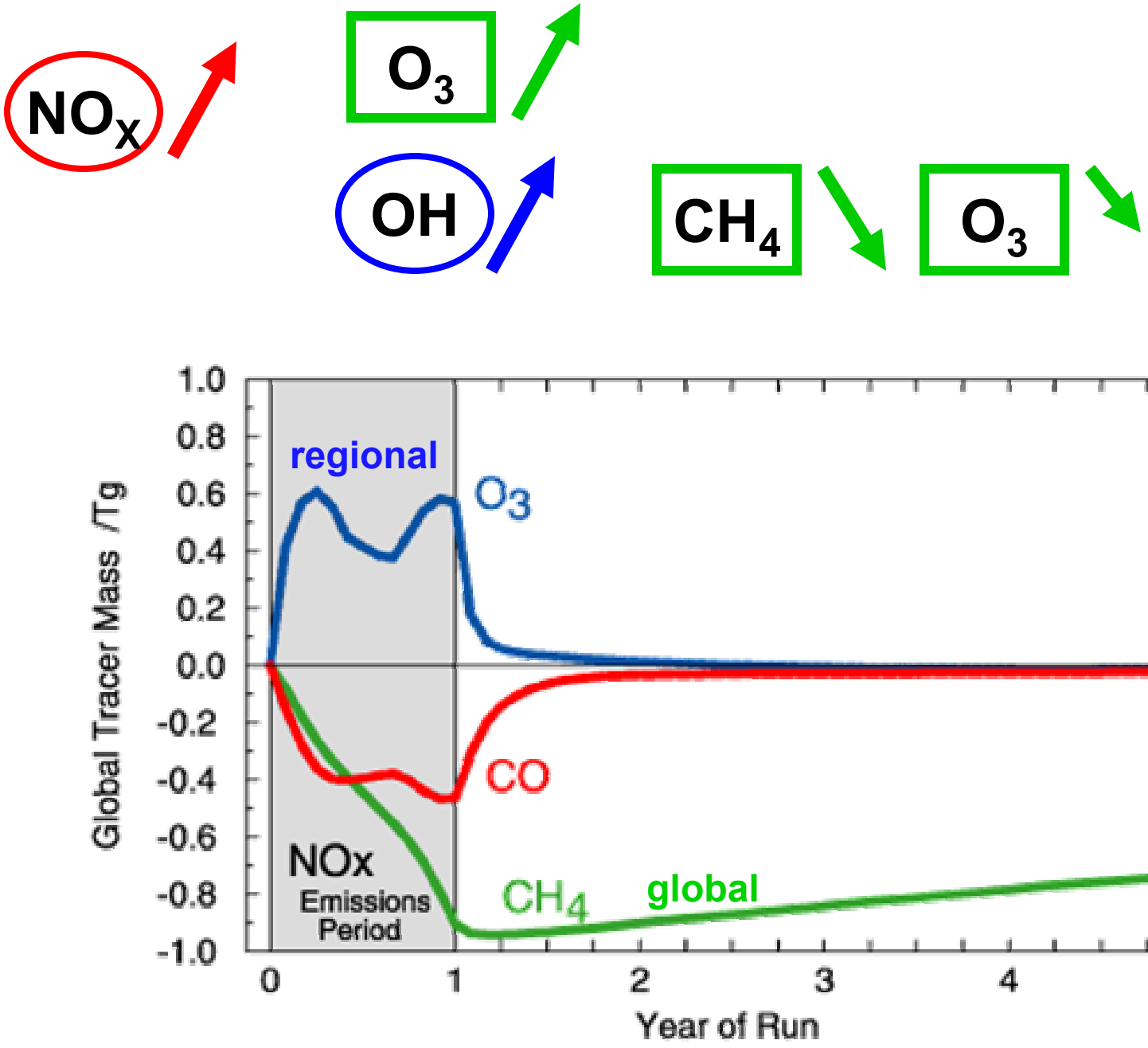
(IPCC, TAR)

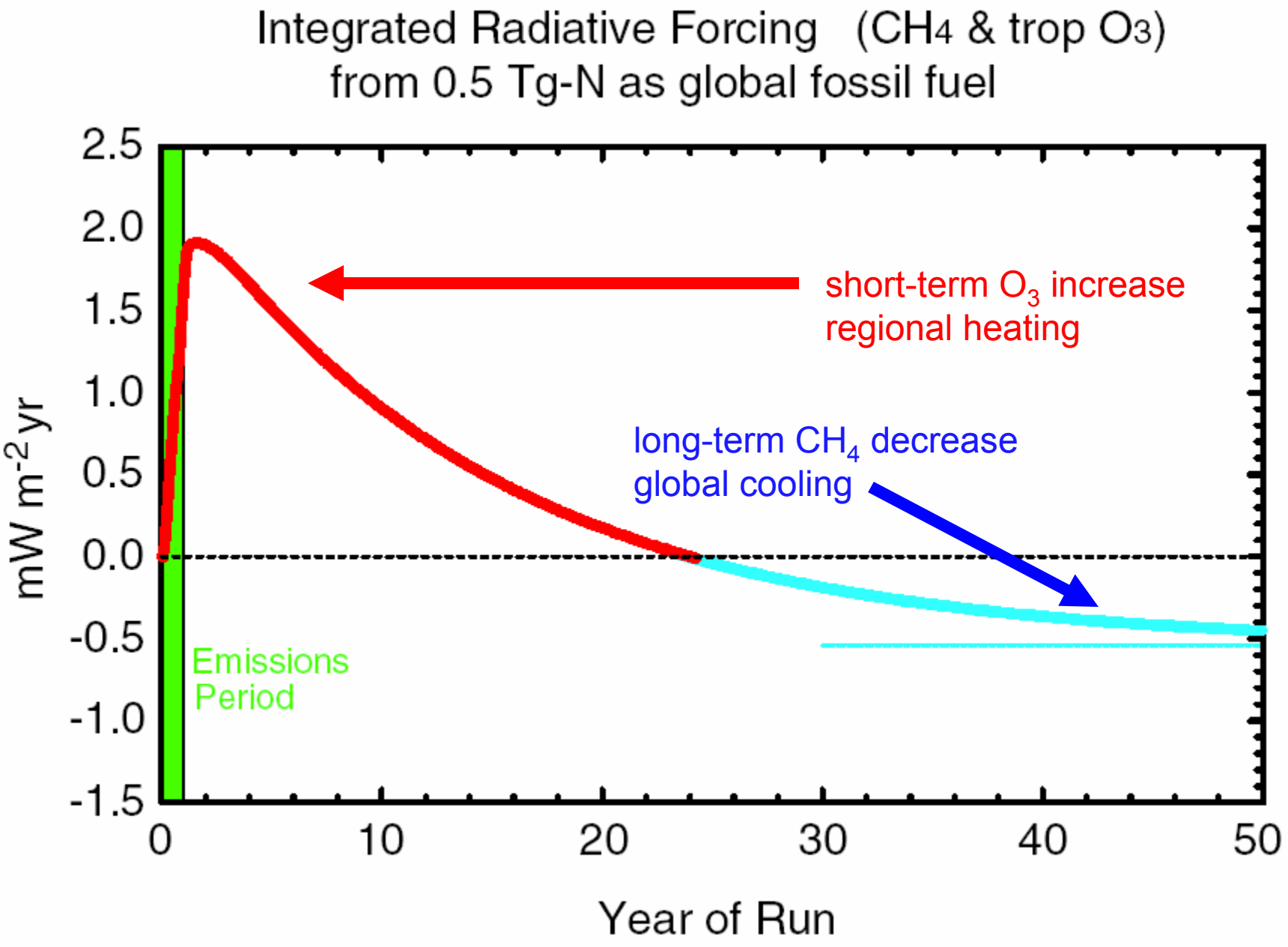
NOx (and O_3 production) stays close to sources

Global Inventory of Nitrogen Oxide Emissions Constrained by Space-based (GOME) Observations of NO2 Columns, *R.V. Martin et al., JGR, 2003.*



Seasonal mean tropospheric NO_2 columns for September 1996 – August 1997.


NO_X
O_3
OH
CH_4
O_3
Global Tracer Mass /Tg
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
regional
O_3
CO
NOx
Emissions
Period
CH_4
global
0
1
2
3
4
5
Year of Run


Integrated Radiative Forcing (CH4 & trop O3)
from 0.5 Tg-N as global fossil fuel
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
mW m-2 yr
0
10
20
30
40
50
Year of Run
short-term O3 increase
regional heating
long-term CH4 decrease
global cooling
Emissions
Period

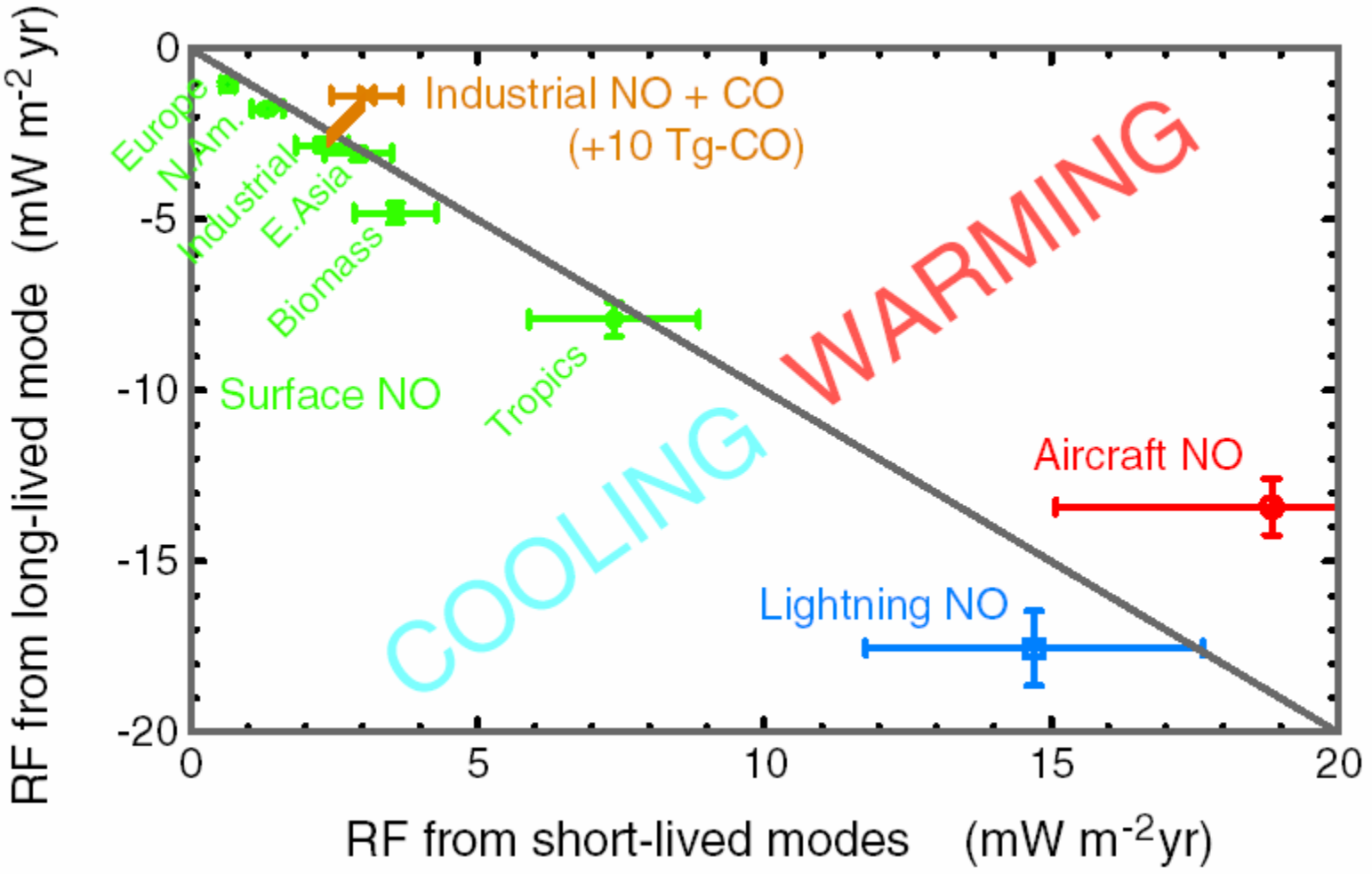
NOx becomes an indirect greenhouse gas

(Wild, Prather, Akimoto, 2001)

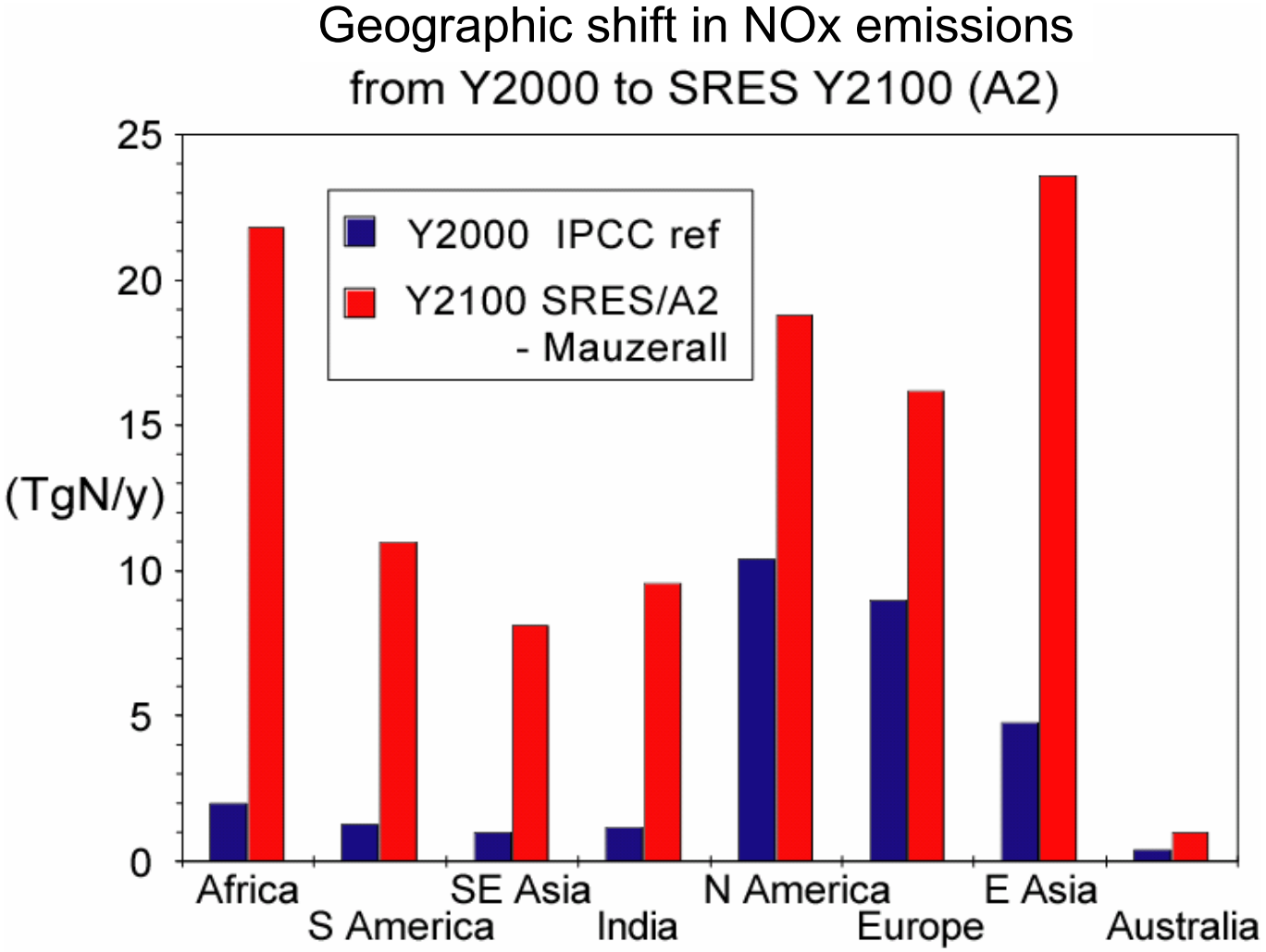
0.5 Tg-N of NOx → short-lived trop-O_3 *vs.* long-lived CH_4 & O_3

tropical, high-altitude emissions have greatest impact

(compare with RF, later)



IPCC / TAR: What about the future ?



IPCC / TAR: SRES A2x scenario for Y2100

⇨ trop O_3 increases patchy, near sources and sunlight

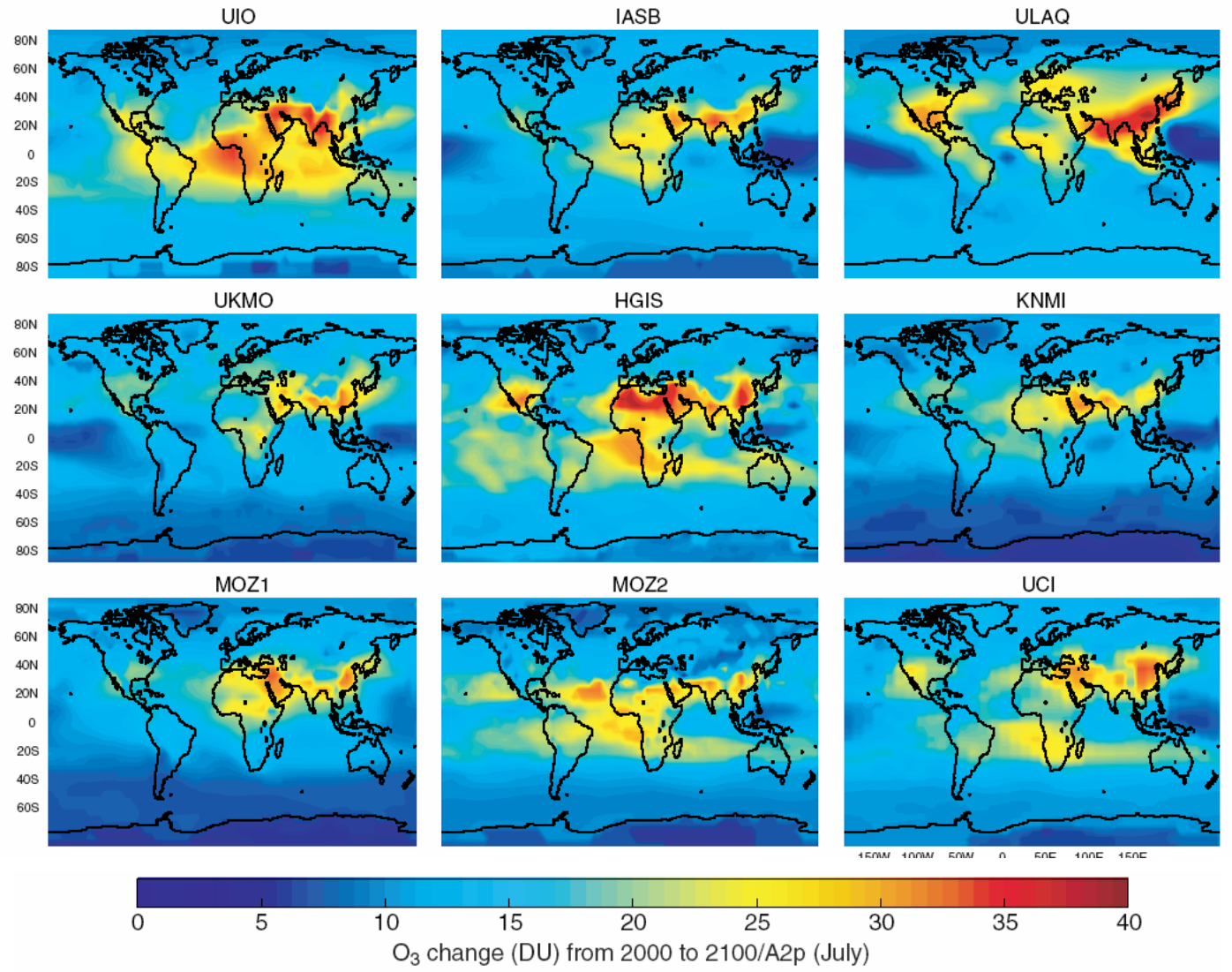
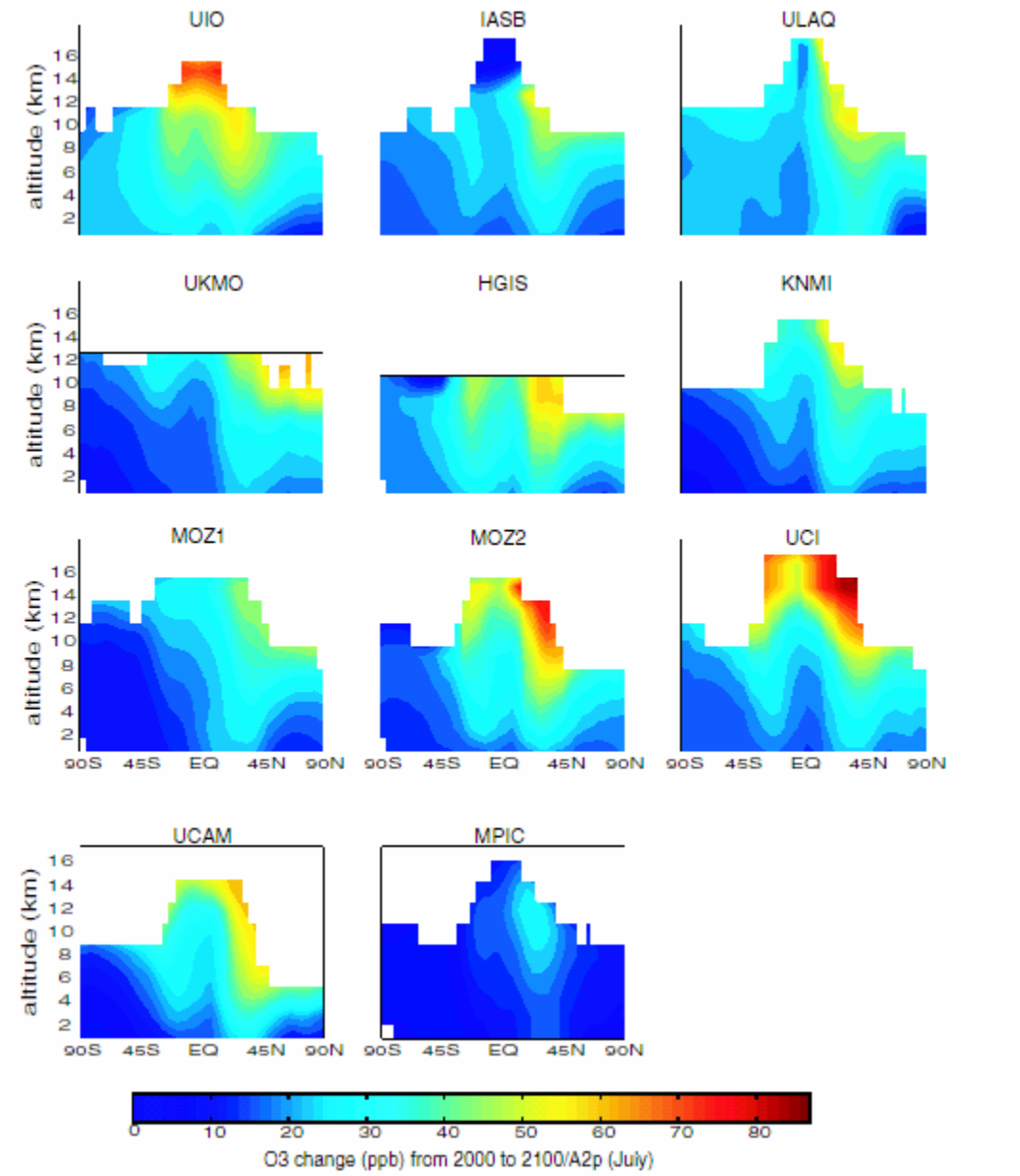


Figure 4.13: July column increase in tropospheric O_3 (DU) as a function of latitude and longitude from Y2000 to Y2100 adopting SRES A2p projections for CH_4, CO, VOC, and NO_x is shown for some OxComp simulations. See Figure 4.12.

IPCC / TAR: SRES A2x scenario for Y2100

⇨ **trop O_3 increases largest in free troposphere**

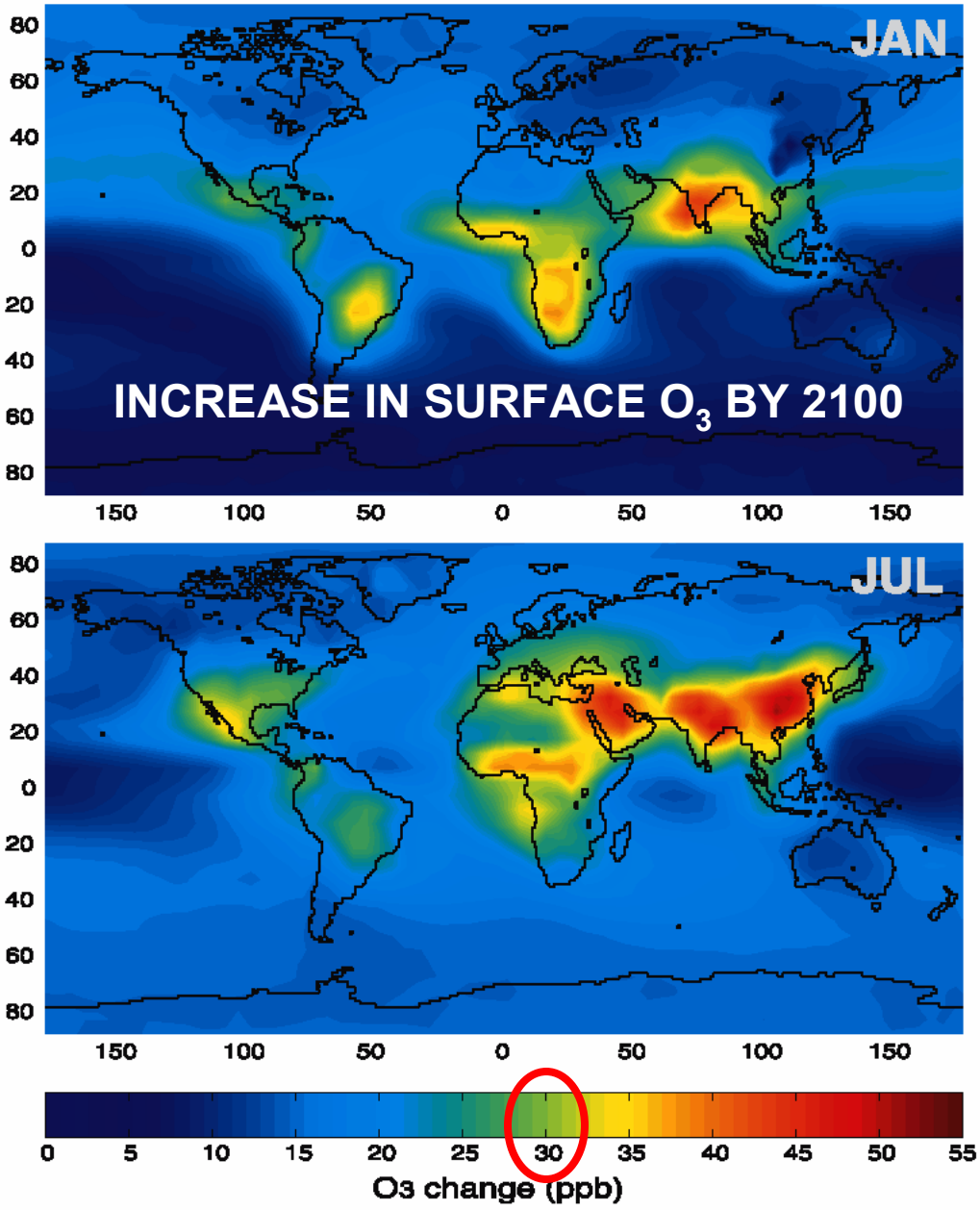


GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 2, 1100, doi:10.1029/2002GL016285, 2003

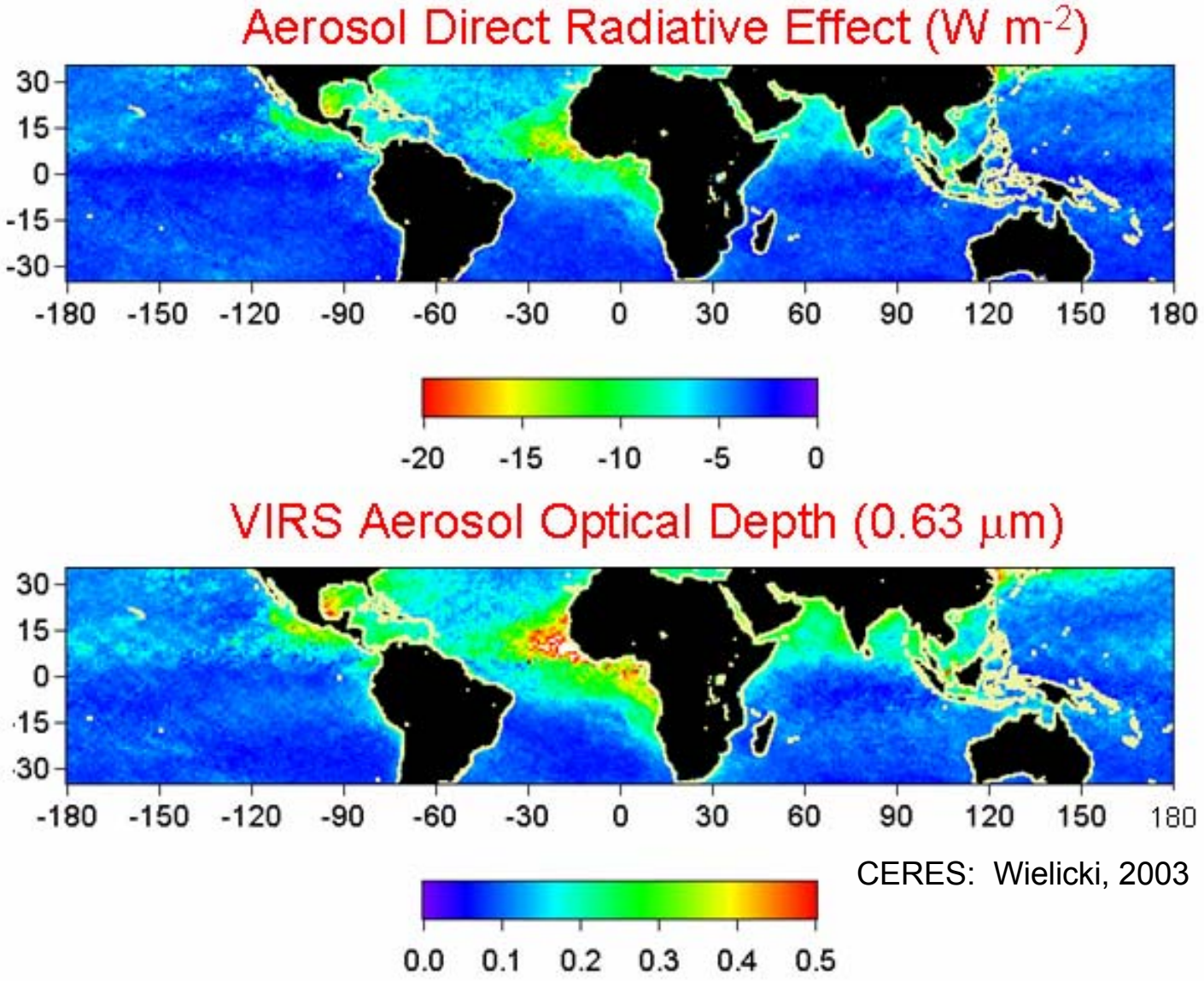
Fresh air in the 21st century?

Michael Prather,[1] Michael Gauss,[2] Terje Berntsen,[2] Ivar Isaksen,[2] Jostein Sundet,[2] Isabelle Bey,[3] Guy Brasseur,[4] Frank Dentener,[5] Richard Derwent,[6] David Stevenson,[6] Lee Grenfell,[7] Didier Hauglustaine,[8] Larry Horowitz,[9] Daniel Jacob,[10] Loretta Mickley, Mark Lawrence,[11] Rolf von Kuhlmann,[11] Jean-Francois Muller,[12] Giovanni Pitari,[13] Helen Rogers,[14] Matthew Johnson,[14] John Pyle,[14] Kathy Law,[14] Michiel van Weele,[15] and Oliver Wild[16]

IPCC (2001). "Changes projected in the SRES A2 and A1FI scenarios would degrade air quality over much of the globe by increasing background levels of O_3. In northern mid-latitudes during summer, the zonal average increases near the surface are about 30 ppb or more, raising background levels to nearly 80 ppb, threatening attainment of air quality standards over most metropolitan and even rural regions, and compromising crop and forest productivity. This problem reaches across continental boundaries since emissions of NOx influence photochemistry on a hemispheric scale."



AEROSOLS: patchiness is well known and observed



CERES: Wielicki, 2003

AEROSOLS: modeled optical depth & RF peaks near sources

Martin R. V., D. J. Jacob, R. M. Yantosca, M. Chin, & P. Ginoux, **Global and regional decreases in tropospheric oxidants from photochemical effects of aerosols**, J. Geophys. Res., 108 (D3), 4097, 2003

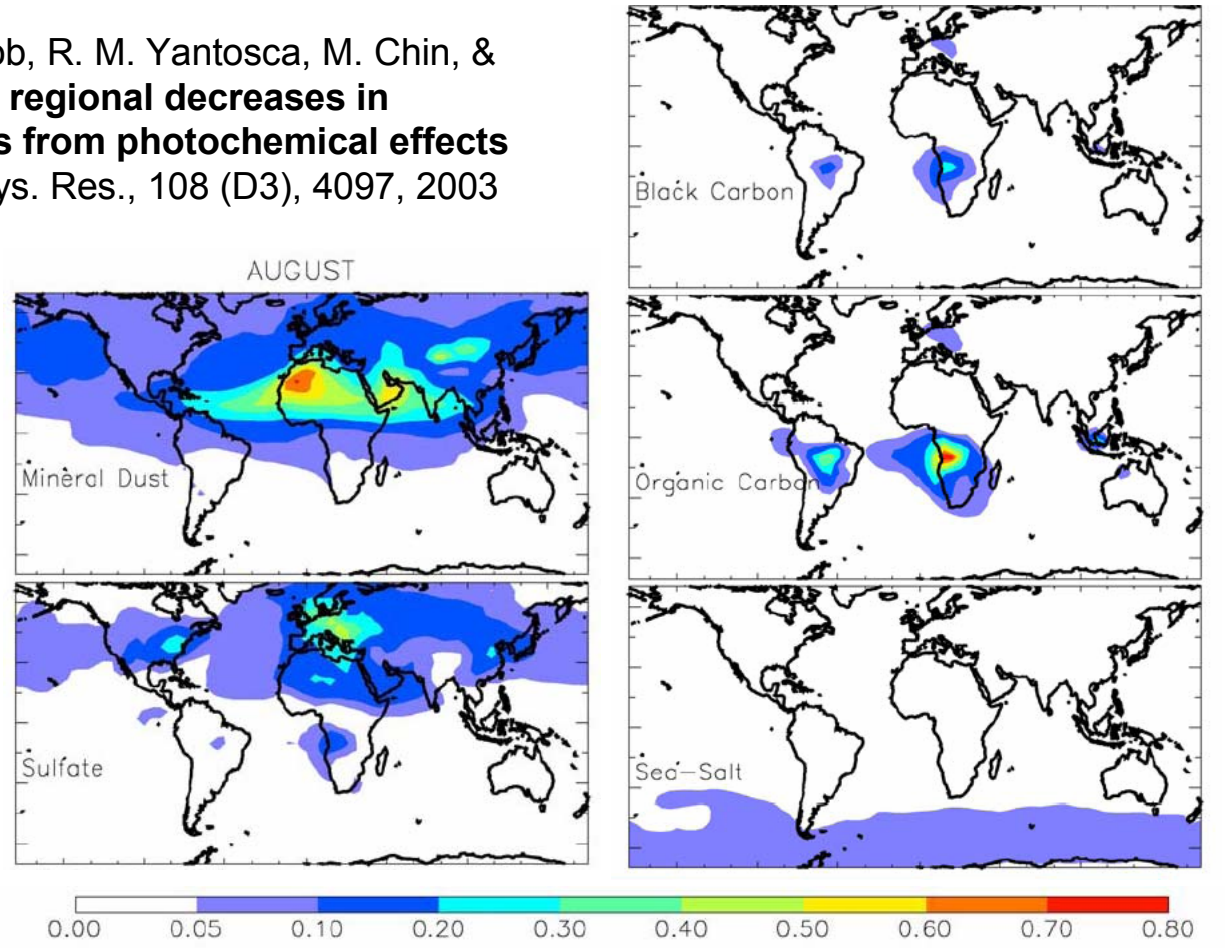


Figure 1: Modeled monthly-mean optical depth at 400 nm of different aerosol types for March 1997 (left column) and August 1997 (right column). Values are calculated from mass concentration fields from *Ginoux et al.* [2001] for mineral dust and *Chin et al.* [2002] for the other aerosol types.

AEROSOLS: even indirect effects peak near sources

Indirect Aerosol Forcing, Quasi Forcing, and Climate Response

LEON D. ROTSTAYN

CSIRO Atmospheric Research, Aspendale, Victoria, Australia

JOYCE E. PENNER

Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, Michigan

1 JULY 2001 JOURNAL OF CLIMATE

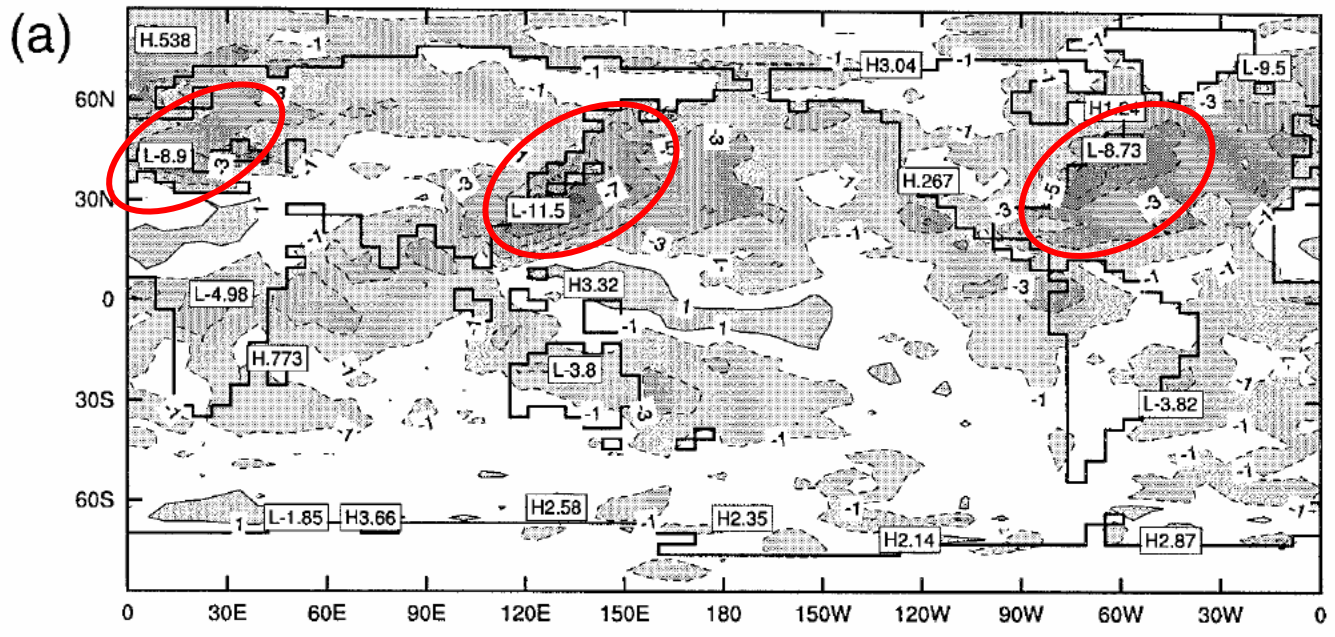


FIG. 1. Annual mean first indirect (Twomey) effect calculated (a) as a quasi forcing based on net TOA radiation,

AEROSOLS: indirect effects on chemistry can reach farther

Bian H., M. J. Prather, and T. Takemura, ***Tropospheric aerosol impacts on trace gas budgets through photolysis***, J. Geophys. Res. 108 (D8), 4242, 2003.

Aerosols affect the global budgets of O_3, OH, and CH_4 in part through their alteration of photolysis rates and in part through their direct chemical interactions with gases (i.e., ‘‘heterogeneous chemistry’’). ... **Globally averaged, the impact of aerosols on photolysis alone is to increase tropospheric O_3 by 0.63 Dobson units and increase tropospheric CH_4 by 130 ppb (via tropospheric OH decreases of 8%).** These greenhouse gas increases lead to an aerosol indirect effect (counting both natural and anthropogenic aerosols) of +0.08 W/m^2. ... The predominant impact is due to the aerosols over land; aerosols over the ocean contribute less than a third to globally integrated changes.

Aerosol-O_3 photolytic coupling gives both increases and decreases in O_3

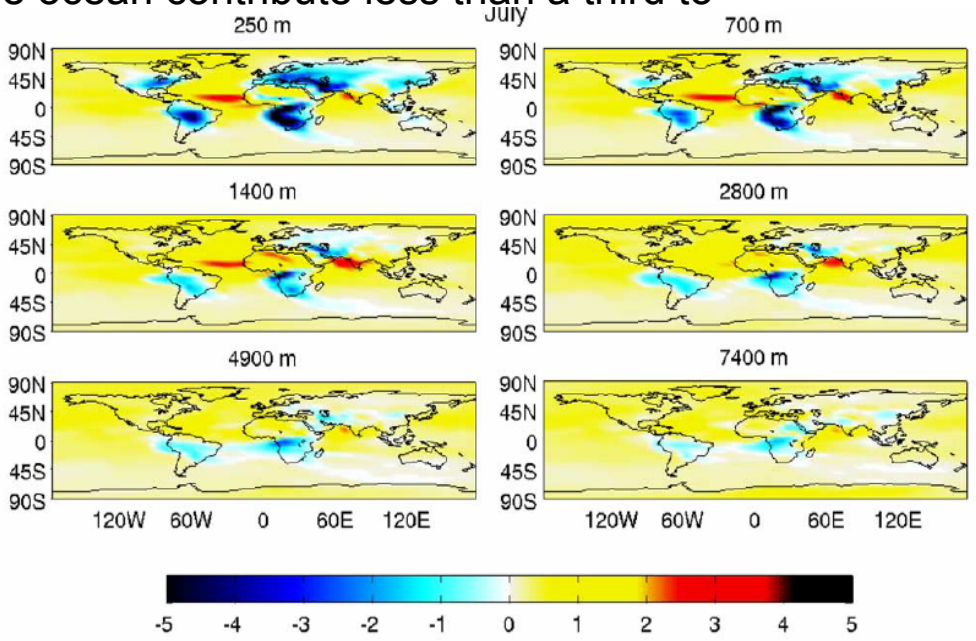


Figure 3. Perturbations to O_3 (ppb) by global aerosol at six atmospheric layers in January and July.

Martin R. V., D. J. Jacob, R. M. Yantosca, M. Chin, and P. Ginoux,
Global and regional decreases in tropospheric oxidants from photochemical effects of aerosols, J. Geophys. Res., 108 (D3), 4097, 2003.

We evaluate the sensitivity of tropospheric OH, O_3, and O_3 precursors to photochemical effects of aerosols not usually included in global models: (1) aerosol scattering and absorption of ultraviolet radiation, and (2) reactive uptake of HO_2, NO_2, and NO_3. ... Aerosols decrease the O3→O(^{1}D) photolysis frequency by 5-20% at the surface throughout the Northern Hemisphere (largely due to mineral dust) and by a factor of 2 in biomass burning regions (largely due to black carbon). Aerosol uptake of HO_2 ... **Annual mean OH concentrations decrease by 9% globally and by 5-35% in the boundary layer over the Northern Hemisphere. Simulated CO increases by 5-15 ppbv in the remote Northern Hemisphere**, improving agreement with observations. Simulated boundary-layer O_3 decreases by 15-45 ppbv over India during the biomass burning season in March, and by 5-9 ppbv over northern Europe in August, again improving comparison with observations. We find that particulate matter controls would increase surface O_3 over Europe and other industrial regions.

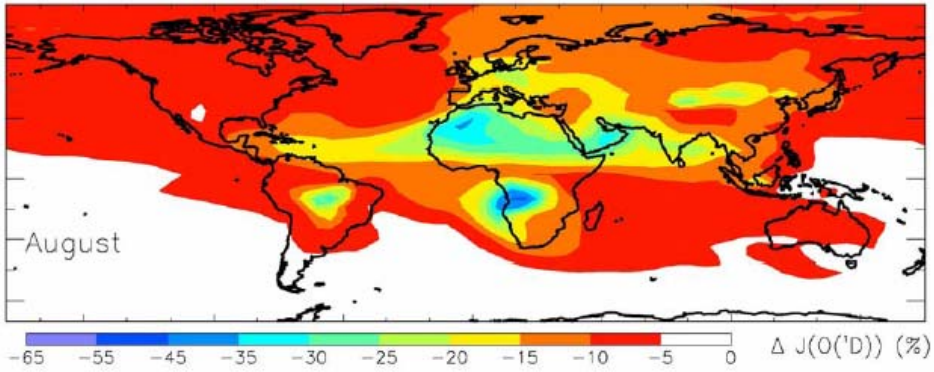


Figure 3: Sensitivity to aerosols of the O_3 → O(^{1}D) photolysis frequency (J(O(^{1}D))) in surface air. Values are monthly-mean model results for March and August 1997.

Short-lived Gases and Aerosols

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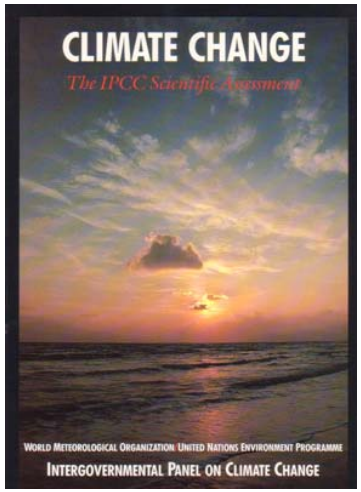


IPCC 1st Assessment Report (1990)

Chapter 2. Shine, Derwent, Wuebbles, Morcrette

RFs summed

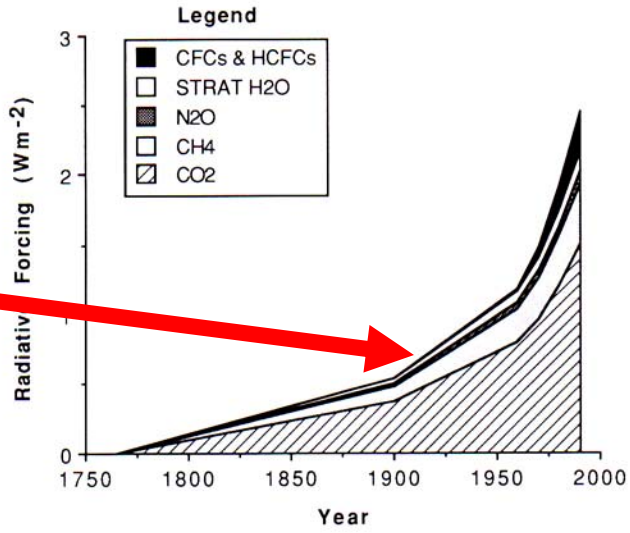
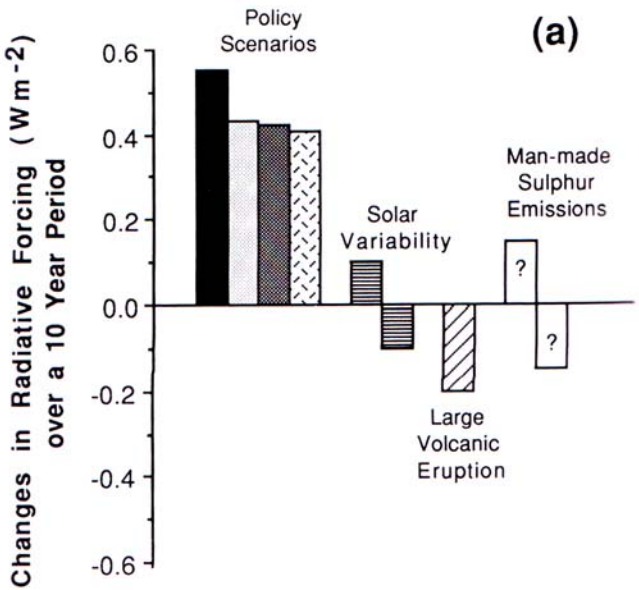
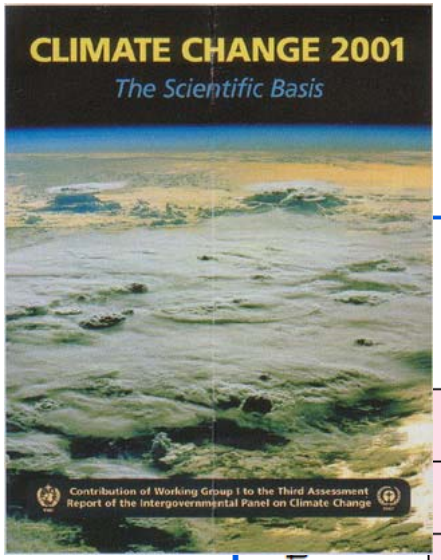


Figure 2.2: Changes in radiative forcing (Wm^{-2}) due to increases in greenhouse gas concentrations between 1765 and 1990. Values are changes in forcing from 1765 concentrations.

? the first IPCC RF bar chart ?



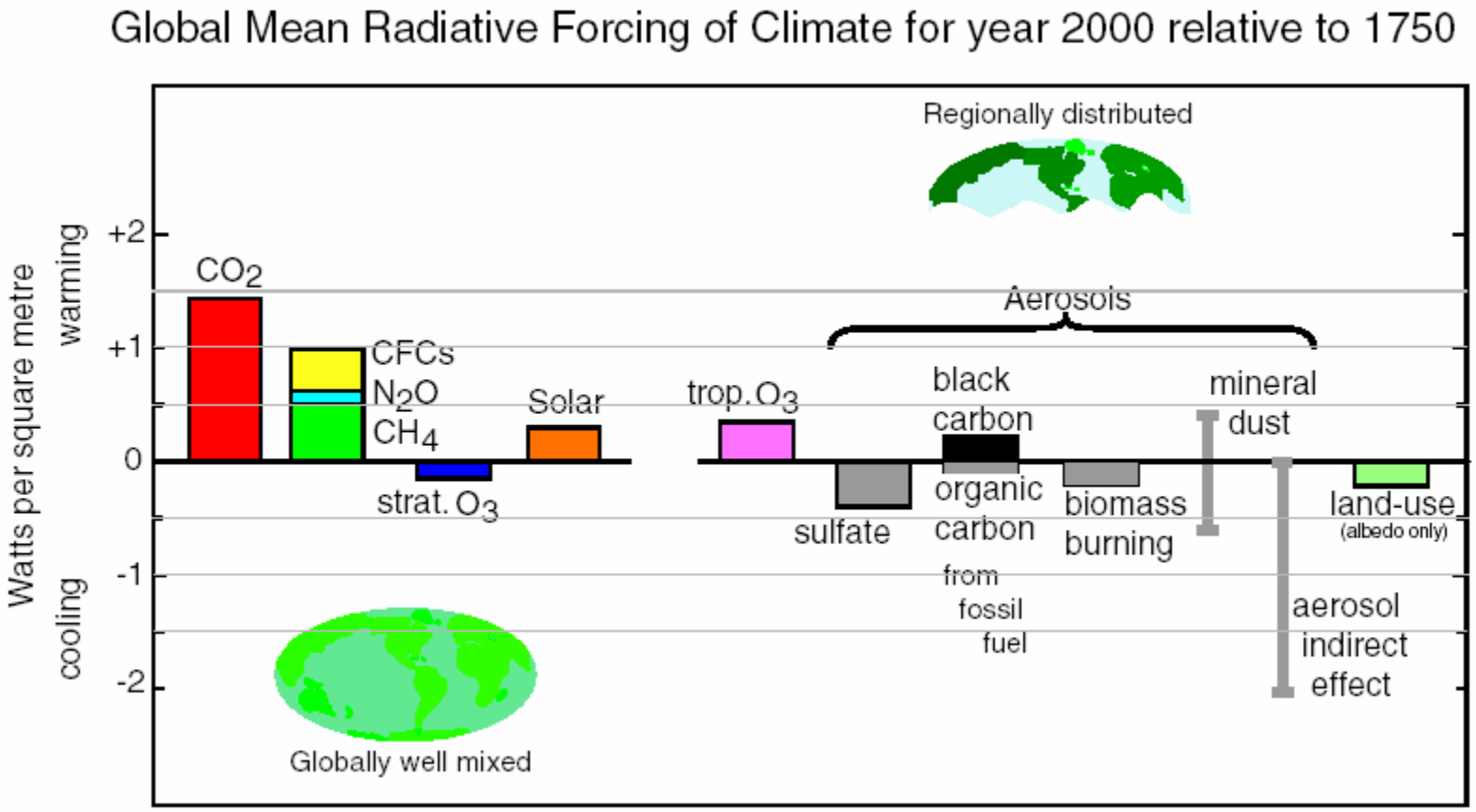


RFs ***not*** summed

The global mean radiative forcing of the climate system for the year 2000, relative to 1750

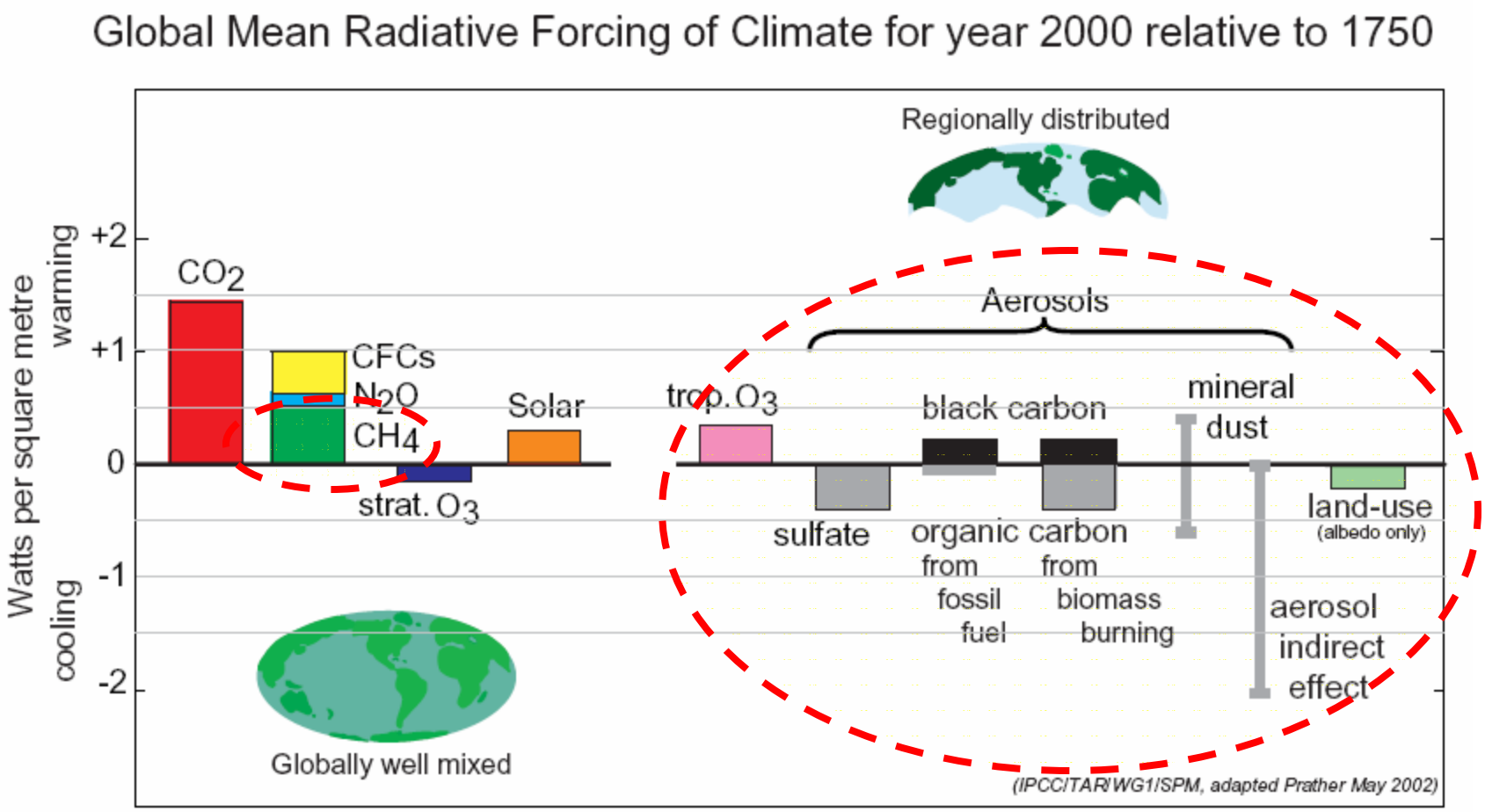
Radiative forcing (Watts per square met
Warming
Cooling
1
0
−1
−2
Halocarbons
N_2O
CH_4
CO_2
Tropospheric ozone
Stratospheric ozone
Aerosols
Black carbon from fossil fuel burning
Sulphate
Organic carbon from fossil fuel burning
Biomass burning
Mineral Dust
Aerosol indirect effect
Aviation-induced
Contrails
Cirrus
Solar
Land-use (albedo) only
High
Medium
Medium
Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Level of Scientific Understanding

Separate global vs. regional (NH) RFs



RFs impacted by short-lived gases and aerosols

(N.B. not included in Kyoto)

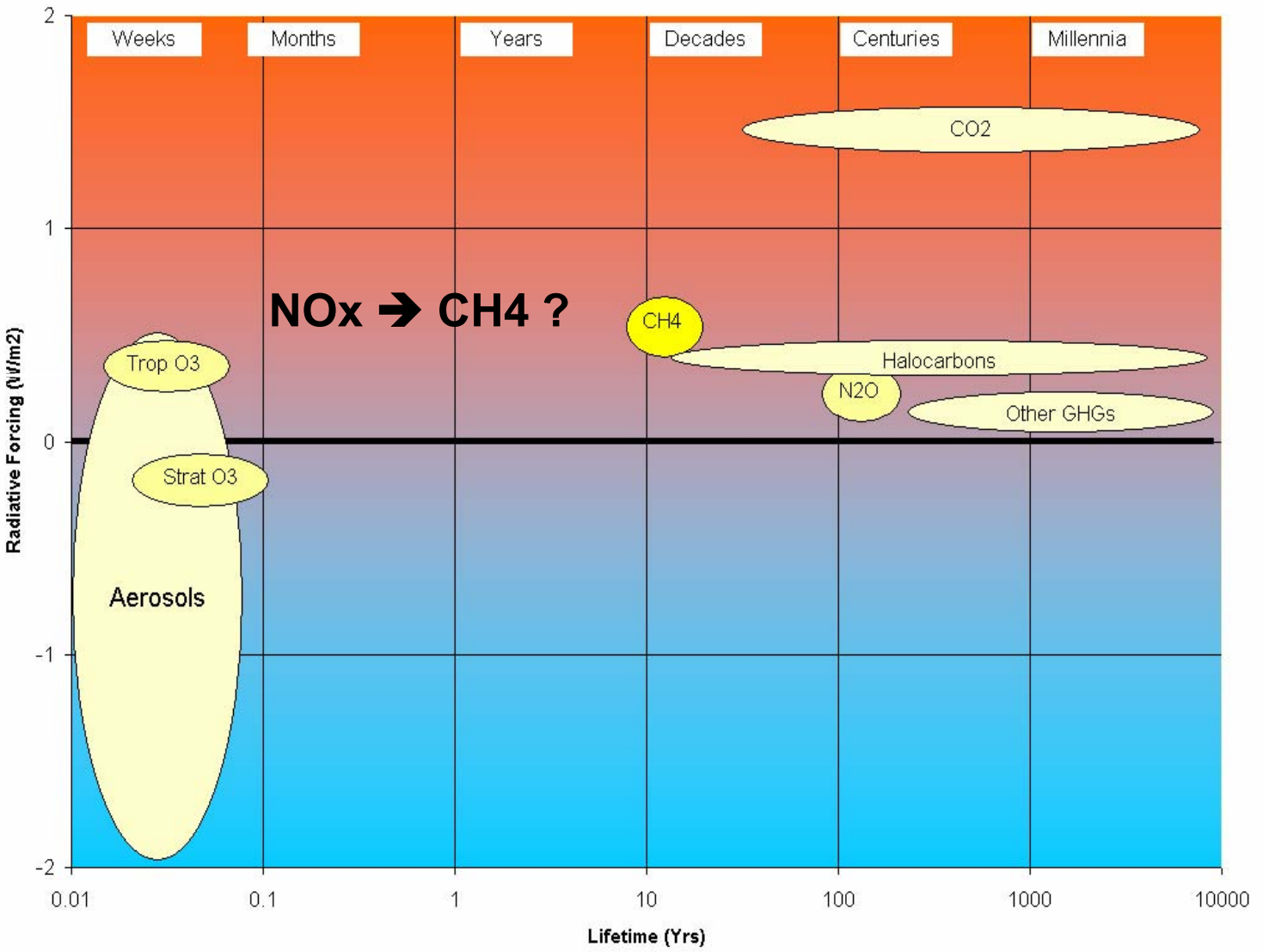


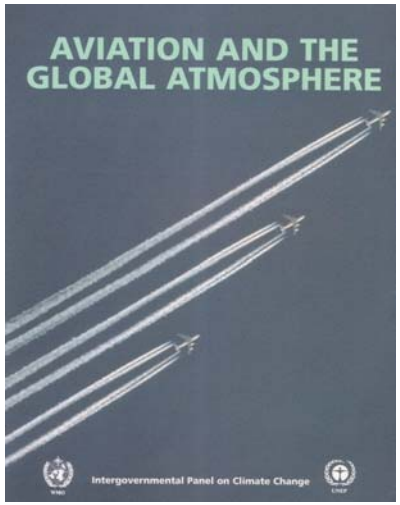
IPCC / AR4 / WGI - ? new bar chart ?

How to convey RF message? stronger emphasis on timescales

Many key warming agents live for decades or more

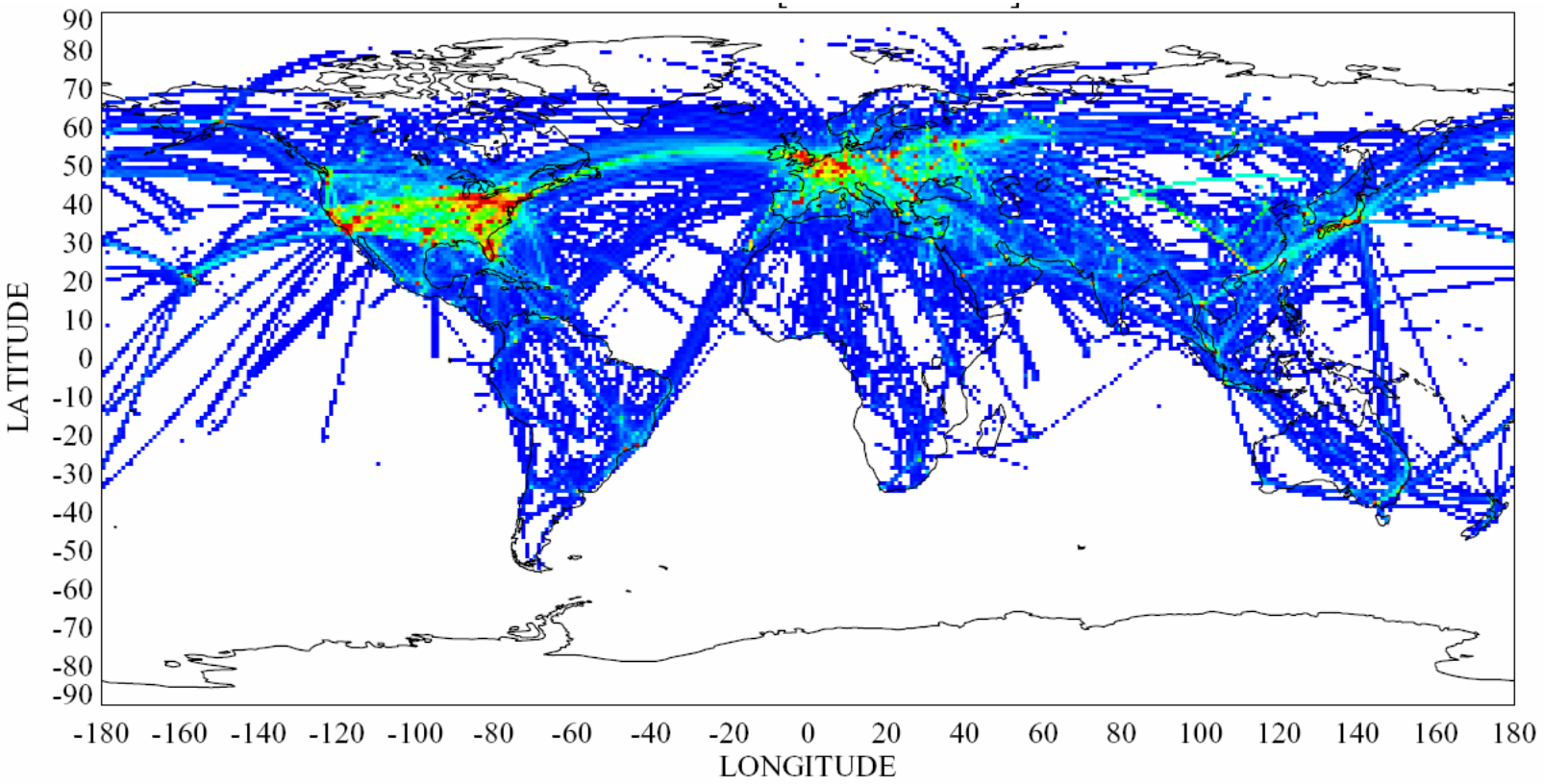
All known cooling agents are short-lived

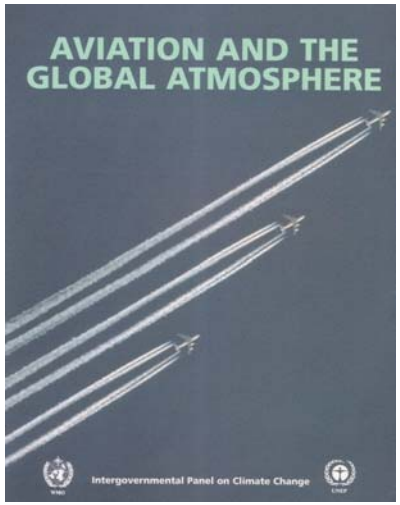




Aviation's impact on the atmosphere is not uniform (IPCC, 1999)

Aviation fuel burn (ca. 1992)





Aviation's impact on the atmosphere is not uniform

O_3 increases (1992-2015)

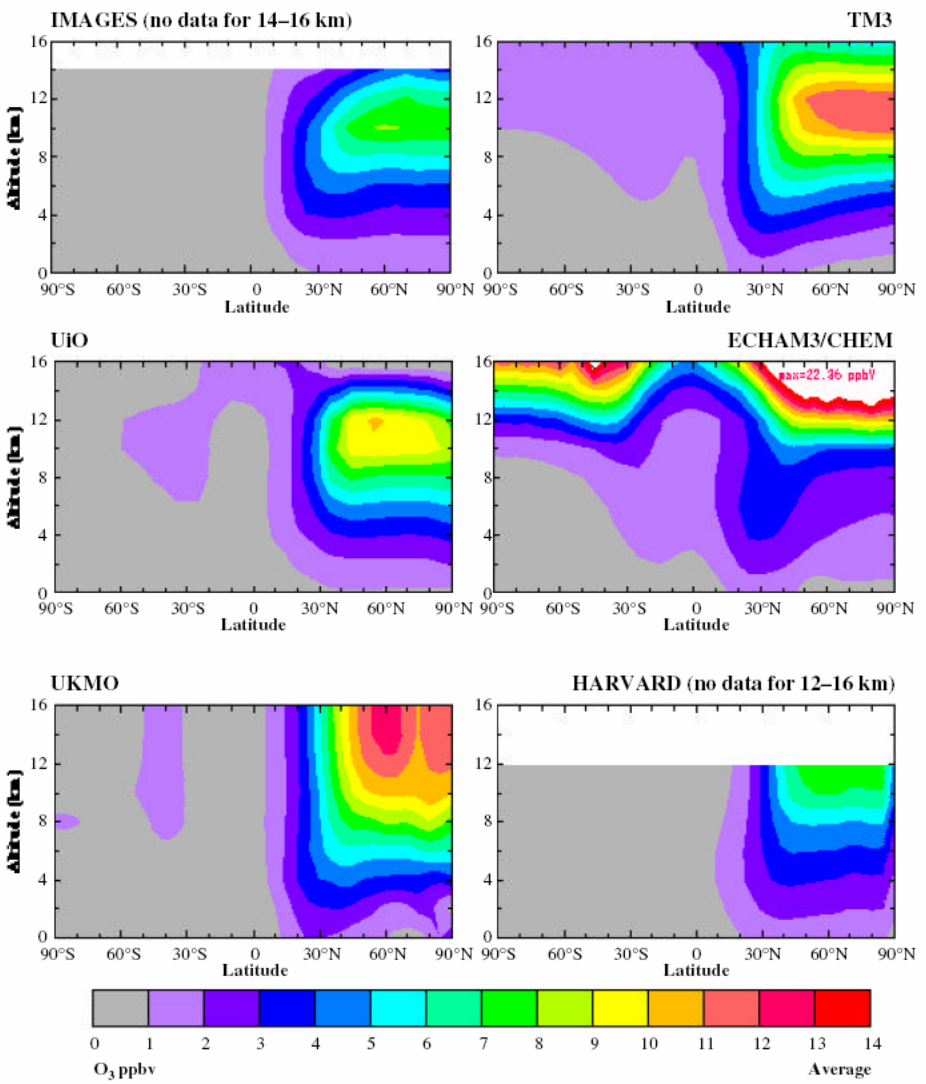


Figure 4-1: Annual (2015) and zonal average increases of ozone volume mixing ratios from aircraft emissions [ppbv] calculated by six 3-D models. The IMAGES/BISAmodel does not give results above 14 km, and the HARVARD model does not give results above 12 km.

Future Development of Contrail Cover, Optical Depth, and Radiative Forcing: Impacts of Increasing Air Traffic and Climate Change

S. MARQUART, M. PONATER, F. MAGER, AND R. SAUSEN

Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany

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1 SEPTEMBER 2003

Aviation's impact on the atmosphere is not uniform

CONTRAILS

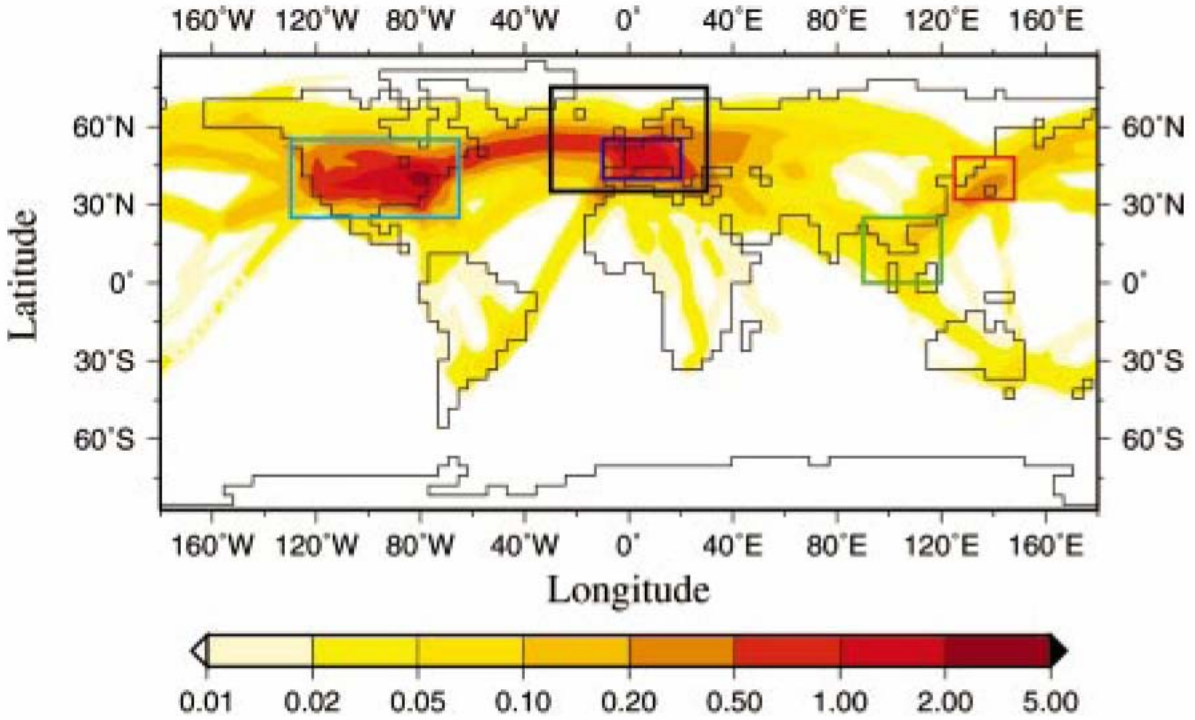
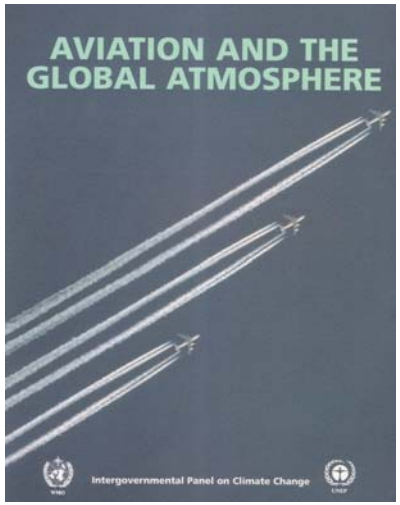


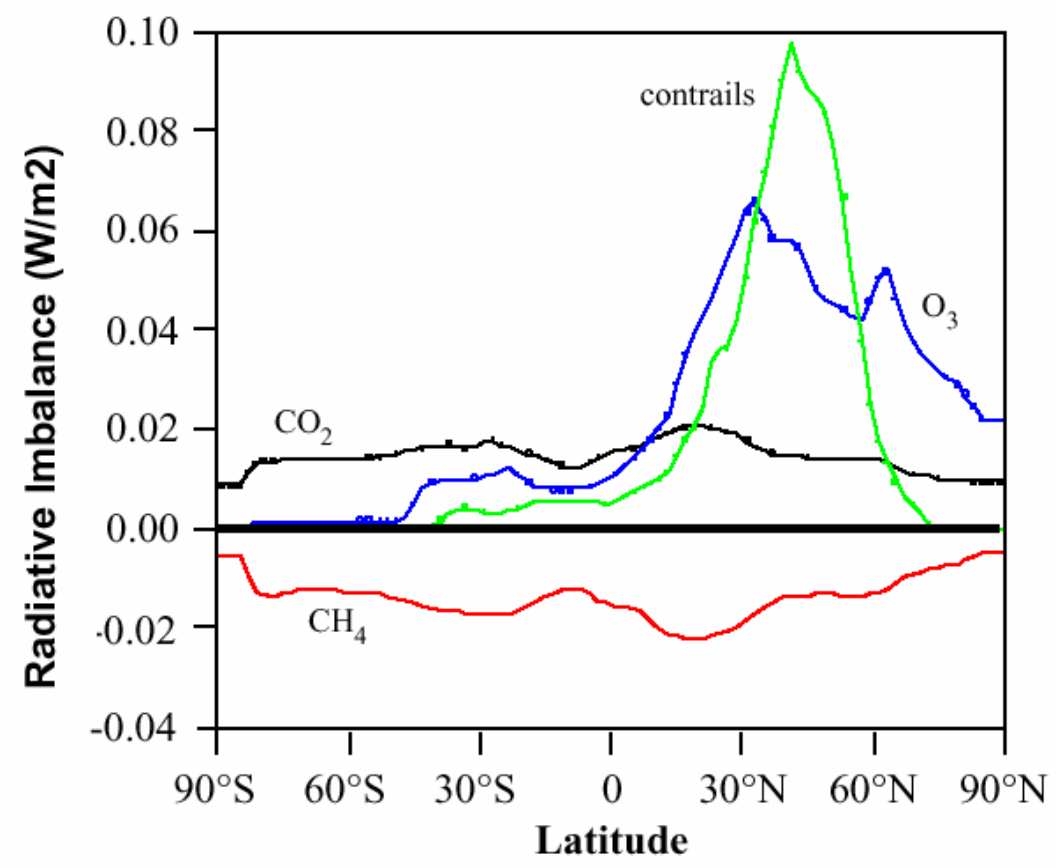
FIG. 2. Annually averaged total contrail cover (%) for the 1992

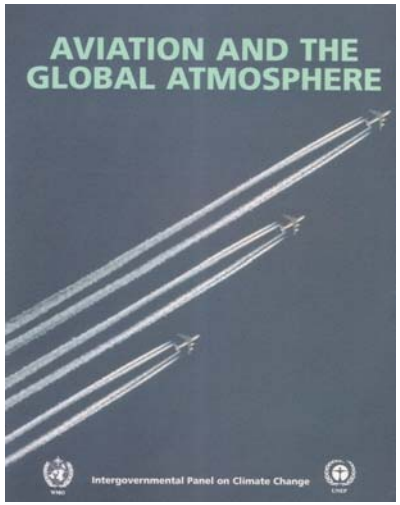
an increase of global annual mean radiative forcing from 3.5 mW m^{-2} in 1992, to 9.4 mW m^{-2} in 2015, and to 14.8 mW m^{-2} in 2050.



The RF from O_3 & contrails is primarily in the NH; that from CO_2 & CH_4 is global.

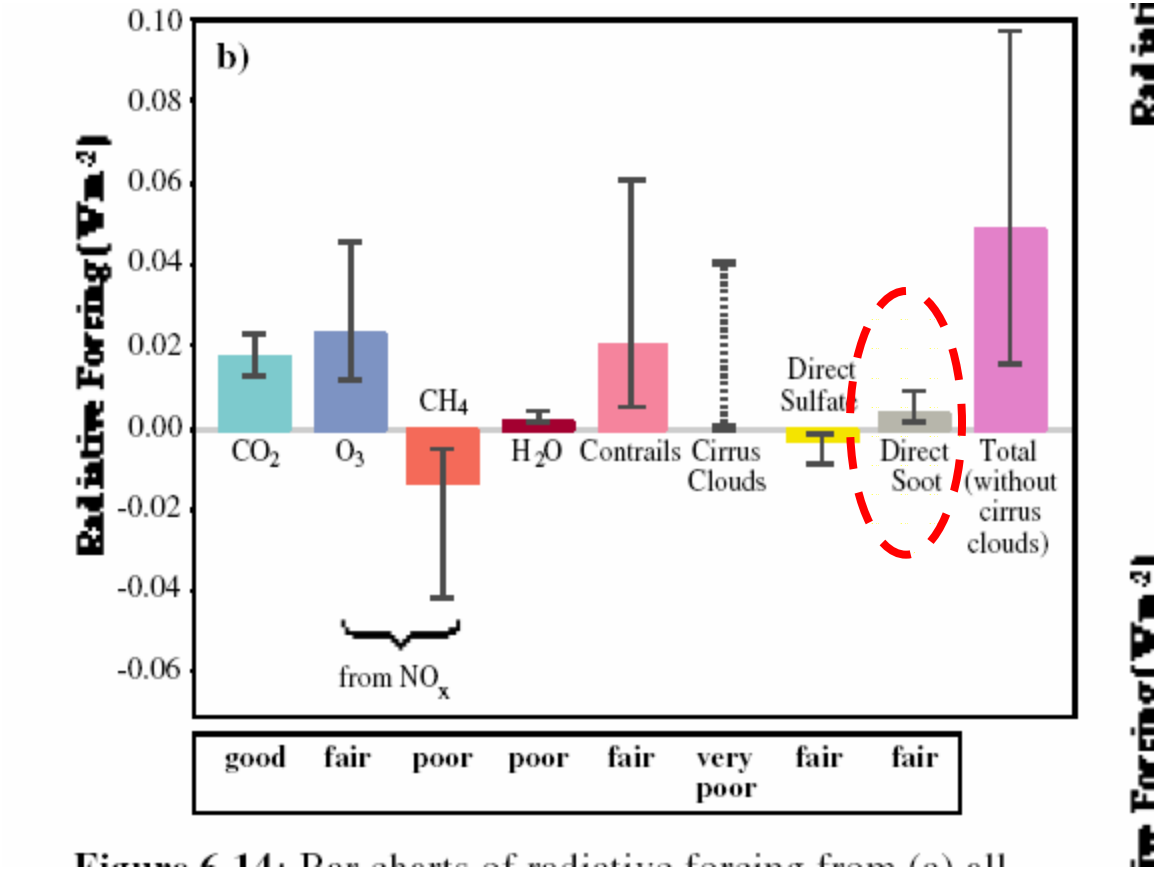
Does this mean different regional climate change ?
– or even a different global mean surface warming ?





Aviation addresses the BC problem

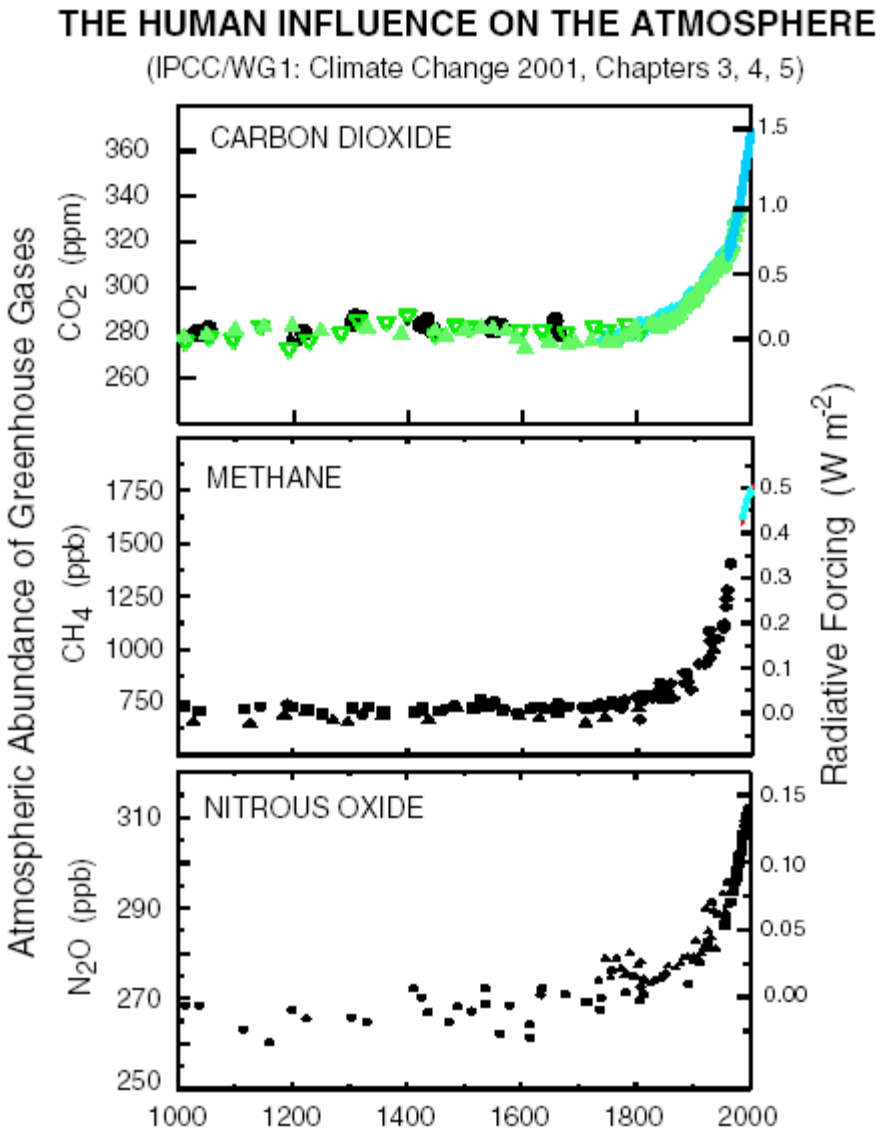
but it is not a major RF



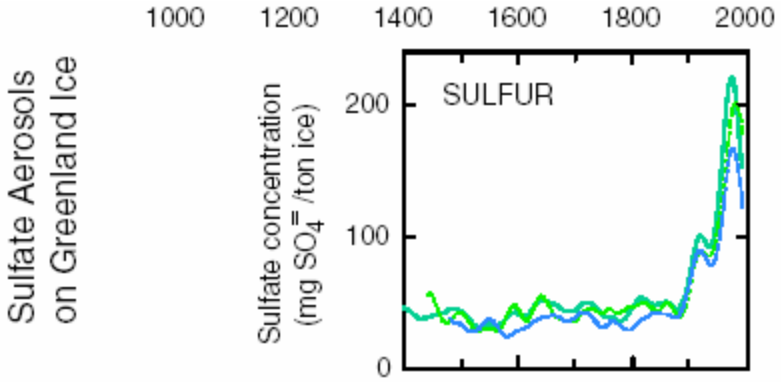
What is the History of Anthropogenic RF ?

OK for long-lived gases

poor for aerosols and O_3



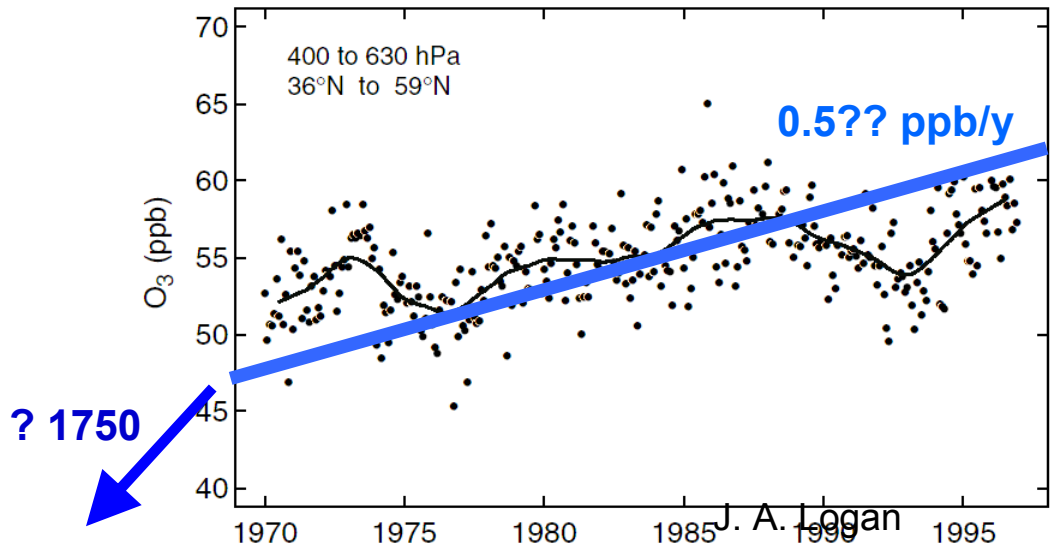
Global sulfate, BC, OC ???



COOLING

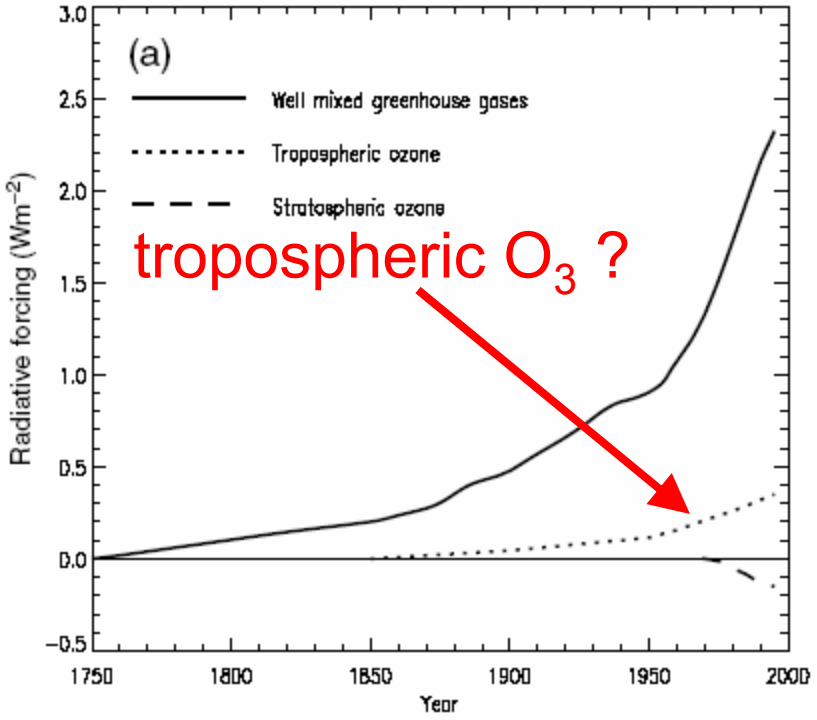
WARMING

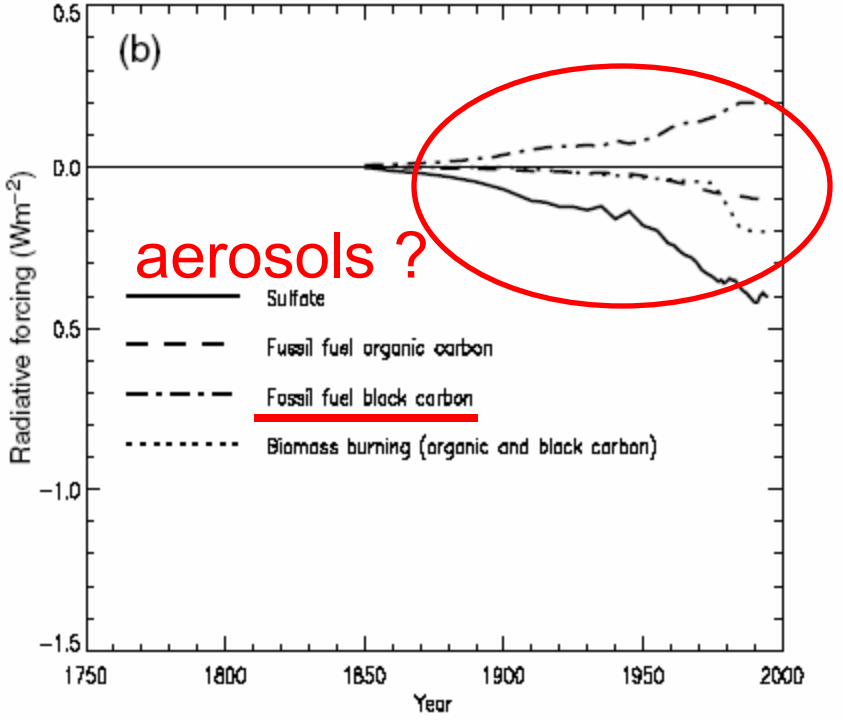
Trends in free tropospheric O_3



1750⇨2000	$\triangle O_3$
"observed"	***25 to 34 DU***
modeled $\triangle CH_4$	+4.6 DU
cause $\triangle NO_X$	+4.1
$\triangle CO$	+1.2
$\triangle VOC$	+0.5

IPCC TAR: How well do we know the history of RF?





Short-lived Gases and Aerosols

Atmospheric Composition and Radiative Forcing

- primary impacts are immediate and close to home
- secondary / indirect impacts are more far reaching

Comparison of Radiative Forcings

- evolution of the bar chart

Climate Response

- climate sensitivity to different types of forcing
- comparing global/regional climate changes

The term "**climate sensitivity**" has different meanings:

Perhaps the earliest modern usage was as

the equilibrium climate sensitivity to doubled CO_2, ΔT,

where the climate sensitivity ΔT, in ^oC, is the increase in global mean surface temperature ($<\Delta T_{surf}>$) after the climate system has come into balance with twice the atmospheric abundance of CO_2.

Carbon Dioxide and Climate: A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide and Climate
Woods Hole, Massachusetts
July 23–27, 1979

Ad Hoc Study Group on Carbon Dioxide and Climate

Jule G. Charney, Massachusetts Institute of Technology, *Chairman*
Akio Arakawa, University of California, Los Angeles
D. James Baker, University of Washington
Bert Bolin, University of Stockholm
Robert E. Dickinson, National Center for Atmospheric Research
Richard M. Goody, Harvard University
Cecil E. Leith, National Center for Atmospheric Research
Henry M. Stommel, Woods Hole Oceanographic Institution
Carl I. Wunsch, Massachusetts Institute of Technology

We have examined with care all known negative feedback mechanisms, such as increase in low or middle cloud amount, and have concluded that the oversimplifications and inaccuracies in the models are not likely to have vitiated the principal conclusion that there will be appreciable warming. The known negative feedback mechanisms can reduce the warming, but they do not appear to be so strong as the positive moisture feedback. We estimate the most probable global warming for a doubling of CO_2 to be near 3°C with a probable error of ± 1.5°C. Our estimate is based primarily on our review of a series of calculations with three-dimensional models of the global atmospheric circulation, which is summarized in Chapter 4.

13

4.1 THREE-DIMENSIONAL GENERAL CIRCULATION MODELS

We proceed now to a discussion of the three-dimensional model simulations on which our conclusions are primarily based. Some of the existing general circulation models have been used to predict the climate for doubled or quadrupled CO_2 concentration. The results of several such predictions were available to us: three by S. Manabe and his colleagues at the NOAA Geophysical Fluid Dynamics Laboratory (hereafter identified as M1, M2, and M3) and two by J. Hansen and his colleagues at the NASA Goddard Institute for Space Studies (hereafter identified as H1 and H2). Some results obtained with the British Meteorological Office model (Mitchell, 1979) were also made available to us but will not be described here because both the sea-surface temperature and the sea-ice distribution were prescribed in this model, thus placing strong constraints on the surface ΔT, whereas it is just the surface ΔT that we wish to estimate.

This definition of **climate sensitivity** is traditional,
but has its problems.

For example, the best current estimate of the RF for a doubling of CO_2 (e.g., 275 to 550 ppm) is 3.7 W m^{-2},

but it has become clear that not all models calculate the same RF for doubled CO_2 **!** This problem is being addressed in the IPCC 4th Assessment Report.

A more recent usage is as

the climate sensitivity parameter, λ,

where the parameter λ, in ^{o}C per W m^{-2}, is the proportionality constant relating the change in RF to the increase in global mean surface temperature ($<\Delta T_{surf}>$) after the climate system has come into balance with change in externally imposed forcing.

$$\Delta T = \lambda \Delta RF$$

The premise that λ is approximately the same for different types of forcings (e.g., CO_2, tropospheric O_3, sulfate aerosols, BC) is the cornerstone behind the RF bar charts, the GWPs used in Kyoto, etc.

the climate sensitivity parameter, λ,

$$\Delta T = \lambda \Delta RF$$

for doubled CO_2, $\Delta RF = 3.7$ W m^{-2},

for a temperature change of $\langle \Delta T_{surf} \rangle = 3^{o}C$ (Charney)

yields $\lambda = 0.8^{o}C$ per W m^{-2}

Can we just sum the ±RFs ?

projected 2050 aviation RF

CO_2	+.074	W m^{-2}	
O_3	+.060		
CH_4	–.045		
contrails	+.100		+.193 W m^{-2}
strat H_2O	+.004		
sulfur	–.009		
soot	+.009		

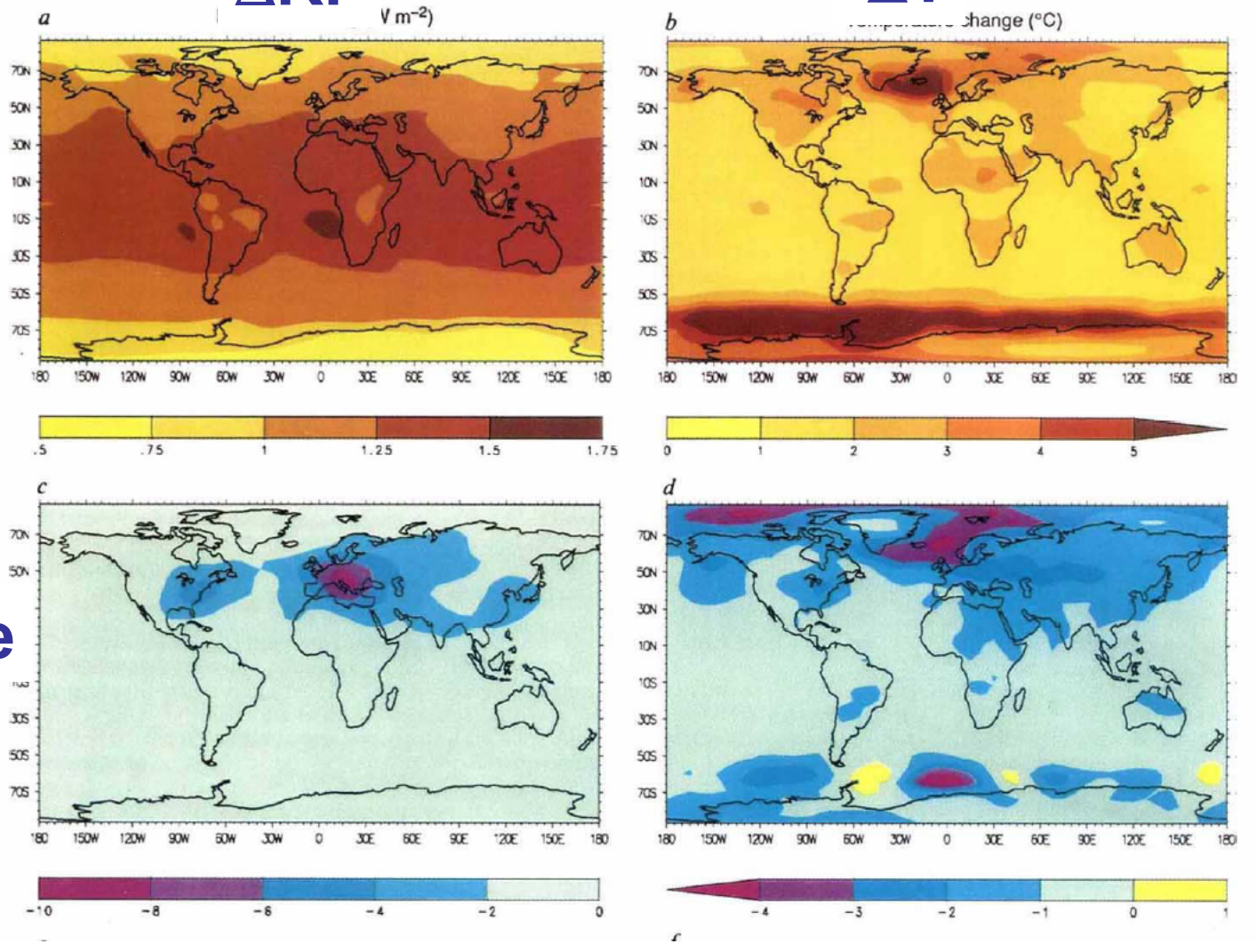
overall 2050 RF

Greenhouse gases	+5.8	
Aerosols	–1.9	+3.9 W m^{-2}

Not if the climate sensitivity parameters λ are different.

Response of the climate system to atmospheric aerosols and greenhouse gases

K. E. Taylor & J. E. Penner



NATURE · VOL 369 · 30 JUNE 1994

Response of the climate system to atmospheric aerosols and greenhouse gases

K. E. Taylor & J. E. Penner*

We find that the global response to aerosol forcing is regionally heterogeneous, with a distribution that is different from the forcing pattern. The simulations also imply that, for equal magnitudes of forcing, the temperature response is markedly greater for carbon dioxide than for aerosol forcing. We conclude that to predict the

Case	ΔF (W m^{-2})	T_s (°C)	ΔT_s (°C)
Global average			
Pre-industrial		12.5	
Present-day CO_2	1.26	14.6	2.1
Present-day sulphate	−0.95	11.5	−1.0
Combined CO_2 and sulphate	0.31	13.3	0.8
Observed climate statistics		14.2*	

How do we calculate λ with climate models?

Hansen et al 1997

- λ varies by 50% among different types and locations of RF (CO_2, solar, CH_4, O_3, aerosols, ...)
- λ for trop O_3, varies from 0.7 – 1.25 due to cloud feedbacks

Rotstayn & Penner 2001

- λ calculated for CO_2 and aerosols, including indirect effects, gives 0.8±0.2 K / W m^{-2}, consistent if indirect included in RF.

Joshi et al 2003

- λ for CO_2 from 3 models ranges from 0.4 to 1.1 K / W m^{-2} !!!
- λ range for CO_2 , solar and trop O_3 for single model: 0.7 – 1.2
- λ larger for strat O_3 (?how is RF defined)

Radiative forcing and climate response

J. Hansen, Mki. Sato & R. Ruedy

J. Geophys. Res. **102,** 6831-6864, 1997.

We examine the sensitivity of a climate model to a wide range of radiative forcings, including changes of solar irradiance, atmospheric CO_2, O_3, CFCs, clouds, aerosols, surface albedo, and a "ghost" forcing introduced at arbitrary heights, latitudes, longitudes, seasons, and times of day. We show that, in general, the climate response, specifically the global mean temperature change, is sensitive to the altitude, latitude, and nature of the forcing; that is, **the response to a given forcing can vary by 50% or more depending upon characteristics of the forcing other than its magnitude measured in Watts per square meter. The consistency of the response among different forcings is higher, within 20% or better, for most of the globally distributed forcings suspected of influencing global mean temperature in the past century, but exceptions occur for certain changes of ozone or absorbing aerosols, for which the climate response is less well behaved**. In all cases the physical basis for the variations of the response can be understood. The principle mechanisms involve alterations of lapse rate and decrease (increase) of large-scale cloud cover in layers that rae preferentially heated (cooled). Although the magnitude of these effects must be model-dependent, the existence and sense of the mechanisms appear to be reasonable. Overall, we reaffirm the value of the radiative forcing concept for predicting climate response and for comparative studies of different forcings; indeed, the present results can help improve the accuracy of such analyses and define error estimates. Our results also emphasize the need for measurements having the specificity and precision needed to define poorly known forcings such as absorbing aerosols and ozone change. Available data on aerosol single scatter albedo imply that anthropogenic aerosols cause less cooling than has commonly been assumed. However, negative forcing due to the net ozone change since the 1979 appears to be have counterbalanced 30-50% of the positive forcing due to the increase of well-mixed greenhouse gases in the same period. As the net ozone change includes halogen-driven ozone depletion with negative radiative forcing and a tropospheric ozone increase with positive radiative forcing, it is possible that the halogen-driven ozone depletion has counterbalanced more than half of the radiative forcing due to well-mixed greenhouse gases since 1979.

Indirect Aerosol Forcing, Quasi Forcing, and Climate Response

LEON D. ROTSTAYN

CSIRO Atmospheric Research, Aspendale, Victoria, Australia

JOYCE E. PENNER

Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, Michigan

The component of the indirect aerosol effect related to changes in precipitation efficiency (the second indirect or Albrecht effect) is presently evaluated in climate models by taking the difference in net irradiance between a present-day and a preindustrial simulation using fixed sea surface temperatures (SSTs). This approach gives a "quasi forcing," which differs from a pure forcing in that fields other than the initially perturbed quantity have been allowed to vary. It is routinely used because, in contrast to the first indirect (Twomey) effect, there is no straightforward method of calculating a pure forcing for the second indirect effect. This raises the question of whether evaluation of the second indirect effect in this manner is adequate as an indication of the likely effect of this perturbation on the global-mean surface temperature.

An atmospheric global climate model (AGCM) is used to compare the evaluation of different radiative perturbations as both pure forcings (when available) and quasi forcings. Direct and indirect sulfate aerosol effects and a doubling of carbon dioxide (CO_2) are considered. For evaluation of the forcings and quasi forcings, the AGCM is run with prescribed SSTs. For evaluation of the equilibrium response to each perturbation, the AGCM is coupled to a mixed layer ocean model.

For the global-mean direct and first indirect effects, quasi forcings differ by less than 10% from the corresponding pure forcing. This suggests that any feedbacks contaminating these quasi forcings are small in the global mean. Further, the quasi forcings for the first and second indirect effects are almost identical when based on net irradiance or on cloud-radiative forcing, showing that clear-sky feedbacks are negligible in the global mean. The climate sensitivity parameters obtained for the first and second indirect effects (evaluated as quasi forcings) are almost identical, at 0.78 and 0.79 K m^2 W^{-1}, respectively. Climate sensitivity parameters based on pure forcings are 0.69, 0.84, and 1.01 K m^2 W^{-1} for direct sulfate, first indirect, and 2 × CO_2 forcings, respectively. The differences are related to the efficiency with which each forcing excites the strong surface-albedo feedback at high latitudes. Closer examination of the calculations of the first indirect effect as a forcing and quasi forcing shows that, although they are in reasonable agreement in the global mean, there are some significant differences in a few regions. Overall, these results suggest that evaluation of the globally averaged second indirect effect as a quasi forcing is satisfactory.

Indirect Aerosol Forcing, Quasi Forcing, and Climate Response

LEON D. ROTSTAYN

CSIRO Atmospheric Research, Aspendale, Victoria, Australia

JOYCE E. PENNER

Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, Michigan

$$\Delta T_s = \lambda \Delta F,$$

	Radiative forcing ($W\ m^{-2}$)		
	Total	ΔT_s (K)	λ ($K\ m^2\ W^{-1}$)
First indirect	−1.46	−1.14	0.78
	−1.35*		0.84*
Second indirect	−1.32	−1.04	0.79
Total indirect	−2.57	−2.24	0.87
Direct sulfate	−0.75	−0.55	0.73
	−0.80*		0.69*
$2 \times CO_2$	3.29	3.52	1.07
	3.48*		1.01*

Climate Dynamics (2003) 20: 843–854
DOI 10.1007/s00382-003-0305-9

M. Joshi · K. Shine · M. Ponater · N. Stuber
R. Sausen · L. Li

A comparison of climate response to different radiative forcings in three general circulation models: towards an improved metric of climate change

1 Introduction

Over the past decade, one of the primary tools with which potential climate change agents have been compared is radiative forcing (e.g. IPCC 1990, 1994, 2001). Radiative forcing is a measure of the radiative impact following some external perturbation, such as a change in greenhouse gas concentration or a change in solar output. The justification for using radiative forcing is that early model results (see e.g. IPCC 1994) had shown that the global mean forcing, ΔF, is approximately related to the equilibrium global mean surface temperature change, ΔT, by

$$\Delta T = \lambda \Delta F \quad (1)$$

where λ is the climate sensitivity parameter. The prime

4.1 Comparison with previous work

Some of our results can be compared with those of Hansen et al. (1997). In their experiments, $\lambda(SG)/\lambda(CG)$ is 0.8, which is similar to the UREAD result. The extratropical forcing gives a 30% higher response than the global forcing, with the tropical one giving a 30% lower response. These are most similar to the UREAD values and show a similar tendency to the ECHAM4 calculations.

Table 1 Illustration of the experiment identifiers for the 12 model runs versus perturbation (top row) and location (first column)

	C (CO_2)	*S* (Solar)	*O* (O_3)
G (global)	CG	SG	OG
T (tropics)	CT	ST	OT
E (extratropics)	CE	SE	OE
N (northern extratropics)	CN	–	ON
S (global lower stratosphere)	–	–	OS

Table 4 Illustration of the possible impact of the pre-industrial to present-day radiative forcings (IPCC 2001) weighted by the effectiveness of each forcing indicated by this study

	Actual forcing (Wm^{-2})	Effective forcing (Wm^{-2})
CO_2	1.46	1.46
Tropospheric O_3	0.35	0.26
Stratospheric O_3	–0.15	–0.23
Solar	0.30	0.27

GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 20, 2047, doi:10.1029/2003GL018141, 2003

An alternative to radiative forcing for estimating the relative importance of climate change mechanisms

Keith P. Shine, Jolene Cook, Eleanor J. Highwood, and Manoj M. Joshi
Department of Meteorology, The University of Reading, Reading, UK

[1] Radiative forcing is widely used to measure the relative efficacy of climate change mechanisms. Earlier general circulation model (GCM) experiments showed that the global-mean radiative forcing could be used to predict, with useful accuracy, the consequent global-mean surface temperature change regardless of whether the forcing was due to, for example, changes in greenhouse gases or solar output. More recent experiments indicate that for changes in absorbing aerosols and ozone, the predictive ability of radiative forcing is much worse. Building on a suggestion from Hansen and co-workers, we propose an alternative, the "adjusted troposphere and stratosphere forcing". We present GCM calculations showing that it is a significantly more reliable predictor of this GCM's surface temperature change than radiative forcing. It is a candidate to supplement radiative forcing as a metric for comparing different mechanisms and provides a framework for understanding the circumstances in which radiative forcing is less reliable. *INDEX TERMS:* 1610 Global Change: Atmosphere

5. Conclusions

[17] This paper has shown that ΔF_{ats} is an excellent predictor of the IGCM's surface temperature change and is greatly superior to the "standard" adjusted radiative forcing. Part of this improvement is due to the fact that it can allow changes in atmospheric parameters that are specific to a particular forcing; the so-called semi-direct forcing whereby absorbing aerosols reduce GCM cloudiness is an obvious example.

[20] The results also indicate the way forward to an improved simple conceptual model of climate change. A widely used model separates forcing from temperature response based on ΔF_a. This has led to a debate as to whether forcings such as the indirect and semi-direct aerosol effects are true forcings as they lead to changes in atmospheric parameters and require the use of a GCM to calculate [e.g., *IPCC*, 2001; *Rotstayn and Penner*, 2001]. The ΔF_{ats} framework is clearer as it distinguishes between forcings that change atmospheric parameters in the absence of surface temperature changes, and climate feedbacks that are ultimately mediated by the surface temperature change.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 109, D16202, doi:10.1029/2004JD004676, 2004

Climate sensitivity to black carbon aerosol from fossil fuel combustion

David L. Roberts and Andy Jones
Hadley Centre for Climate Prediction and Research, Met Office, Exeter, UK

Received 23 February 2004; revised 17 May 2004; accepted 9 June 2004; published 18 August 2004.

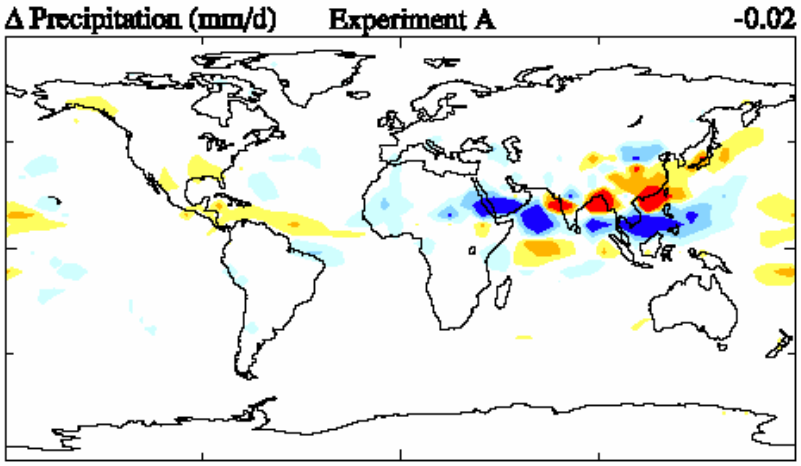
[1] Black carbon aerosol particles from fossil fuel combustion are good absorbers of solar radiation and hence exert a positive radiative forcing, reinforcing the warming due to anthropogenic increases in CO_2 and other greenhouse gases. However, it is unclear how the climate sensitivity to black carbon aerosol forcing compares with the sensitivity to greenhouse gas forcing. Here we investigate this question using the HadSM4 configuration of the Hadley Centre climate model, extended by the addition of interactive black carbon and sulphate aerosol schemes. The results confirm earlier suggestions that the climate sensitivities are not necessarily similar and indicate that the black carbon sensitivity may be weaker. Possible reasons for this are explored by studying several feedback mechanisms operating in the model. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0368 Atmosp Troposphere—constituent transport and chemistry; 1620 Global C

6. Conclusions

[47] This study has investigated the climate sensitivity to anthropogenic emissions of fossil fuel black carbon aeroso (λ_{BC}), using the "slab" model HadSM4 extended to include interactive BC and sulphur cycle schemes. The climate sensitivity to doubling CO_2, λ_C, was also explored in a parallel experiment. It transpired that in this model λ_{BC} is significantly less than λ_C, due to differences in the strengths of several feedback processes. The realism of these differences has been assessed: Some are physically reasonable,

Regional forcings & response present an assessment challenge

--especially aerosols--



Menon et al. (2002):

black carbon and Asian precipitation.

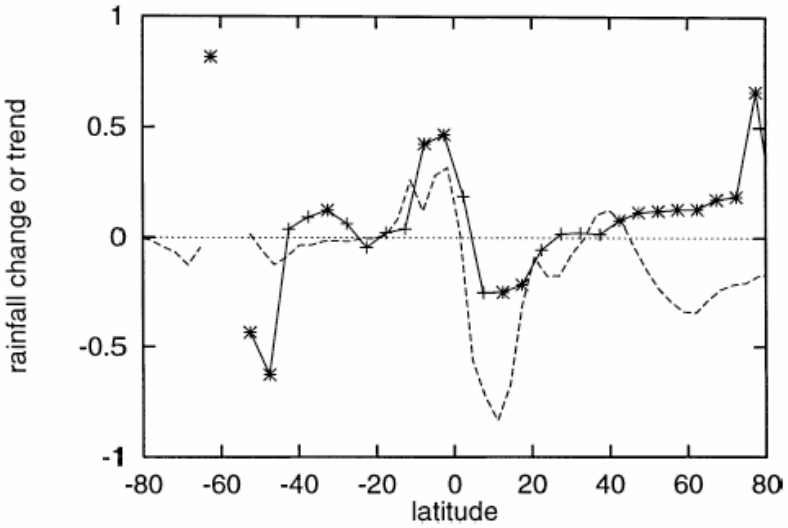


FIG. 5. Zonally averaged trend in observed annual-mean precipitation over land for the period 1901–98 in mm day^{-1} century^{-1} (solid line) and zonally averaged difference in annual-mean precipitation over land between the PD and PI runs in mm day^{-1} (dashed line). Points at which the observed trend is (is not) significant at the 5% level are shown as asterisks (pluses).

Rostayn and Lohmann (2002):

aerosols link to African drought

Aerosols plus tropospheric O_3 = regional climate change

Will we move to assessing regional climate impacts
from regional RF sources?

Yes, the capability is or will soon be there.

How does this fit under the FCCC premise that “we are all in the same boat“ ?

How will this overlap with the convention on Long-Range Transboundary Air Pollution ?

Michael is confounded by regional climate change.